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News from the IPO

W. John Gould, Director, WOCE IPO

The broad range of articles that appear in this Newsletter are testimony to the fact that WOCE is well and truly under way and that new and exciting results are starting to appear. Perhaps surprisingly, since the main Atlantic thrust is scheduled for 1996–97, we have a number of articles on Atlantic results.

Planning for the Atlantic work in 1997 has been very active. John Toole and Harry Bryden produced a draft strategy for a rapid resurvey of the Atlantic based largely on a reoccupation of IGY lines in order to document water mass changes since the late 1950s. The Bryden/Toole plan, together with an Atlantic float strategy were discussed at the Core Project 3 meeting in Fuengirola. The input from all of these discussions was then used in a US WOCE/ACCP/International planning meeting in Princeton in May. The report of that meeting will form the basis of a scientific rationale and detailed implementation strategy for the Atlantic that will be refined during the summer.

Data analysis and interpretation and the production of data sets for model assimilation will be a major concern of the later stages of the WOCE observation period (to the end of 1997) and far beyond (to 2005). This has been recognised by the USA who are funding our new IPO staff member Peter Saunders (best known to most of you, before his retirement, for his research work at IOSDL). Peter's job in the IPO will be to provide oversight and guidance on data and modelling issues. You will see from his article in this issue that he is already making an important contribution.

In order to have a WOCE organisational structure appropriate for the latter stages of WOCE, some changes are planned. Core Projects 1 and 2 will be replaced by a Global Committee and CP3 will become a Gyre Scale Committee. New terms of reference are under discussion and will be ratified at the next WOCE SSG meeting in October. The Data Management Committee will become a Data Products Committee under its new co-chairs Eric Lindstrom and Herlé Mercier. Changes to other committees are in hand and will be reported on later in the year.

The beginning of June saw a major change in the SSG. Allyn Clarke who had been Chair and Co-Chair of the SSG since 1990 stood down and has been replaced by Breck Owens (WHOI) and John Church (CSIRO, Hobart). Allyn's chairmanship has seen WOCE progress from planning to implementation and the present healthy state of WOCE owes much to his dedication and hard work. We all owe him a debt of gratitude. However, Allyn has been appointed as Vice-Chair of the Joint Scientific Committee of WOCE's parent body the World Climate Research Project, so he will still be keeping a close interest in our activities.

It is gratifying to see so many articles being submitted to the International WOCE Newsletter. Keep them coming. This is the last that will have been edited by Ilse Hamann whose secondment to the IPO ends in September. I would like to thank her for what she has done for the IPO, and in particular in stimulating discussions and interaction between scientists involved in the West Pacific.

And finally........ The IPO is starting to plan its move, scheduled for summer 1995, to the newly built Southampton Oceanography Centre. The Centre is a joint venture between IOSDL and the University of Southampton. There will be an inevitable disruption but our plan is to ensure that the IPO move will be as transparent as possible to the outside world.

MEETINGS TIMETABLE 1994

August 15–19	"The South Atlantic: Present and Past Circulation" Symposium (plus Deep Basin Experiment Meeting), Bremen.
September 13–15	WOCE Data Products Committee (DPC-7), Southampton, UK.
September 19–21	WOCE Numerical Experimentation Group (NEG-9), Los Alamos, NM.
September 26–30	CLIVAR SSG-3, London, UK.
October 3–7	JSC Ocean Observing System Development Panel (OOSDP-X), Dallas, TX.
October 12–14	WOCE Scientific Steering Group (WOCE-21), Kiel.
October 15	WOCE EXEC-9, Kiel.
October 18–19	Intergovernmental WOCE Panel (IWP-3), Paris.
October 24-26	WOCE Core Project 3 (CP3-8), WHOI, USA
November 1–4	US WOCE SSC, College Station, TX.
November 2–4	WOCE Hydrographic Programme Planning Committee (WHP-13), Kaohsiung, ROC.
November 2–4	WOCE/TOGA Surface Velocity Programme Planning Committee (SVP-7), La Jolla, CA.
November 7–10	Arctic Climate System Study (ACSYS) SSG, Bergen, Norway

Cross-Equatorial Flow of the Atlantic Deep Western Boundary Current

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SOFAR float trajectories were recently obtained in the equatorial Atlantic at depths of 800 m in the Antarctic Intermediate Water and at 1800 m and 3300 m in the North Atlantic Deep Water. The fundamental issue investigated is the exchange of water between the North and South Atlantic Oceans. Water mass properties including freon imply that deep western boundary current (DWBC) water splits near the equator, with a part of it flowing eastward along the equator and another part continuing southward along the western boundary. It is not known to what extent the tongue of freon lying along the equator near 1700 m is due to advection or to enhanced mixing. Thus a secondary issue investigated is the nature of the connection between the DWBC and flow along the equator.

The DWBC is the major pathway by which cold deep water flows southward into the South Atlantic and, eventually, into the Pacific and Indian Oceans. The warm upper layer in the Atlantic, including the intermediate water, is thought to flow northward in compensation for the deep water. Schmitz and Richardson (1991) identified 13 Sv of upper level water from the South Atlantic flowing northward across the equator into the Gulf Stream. Neither flow had previously been directly measured crossing the equator. This large-scale thermohaline circulation results in a northward heat flux through the Atlantic which is important for world climate. An improved understanding of the thermohaline circulation and its variability is required in order to design a scheme to measure variations in the meridional flux of heat in the oceans and variations in climate.

The results described here are a continuation of an experiment begun in January 1989. A technical report (Richardson *et al*., 1992) and two papers (Richardson and Schmitz, 1993; Richardson *et al*., 1994) describe results from the first 21 months of data. This report summarizes trajectories at 1800 m from the whole experiment, January 1989–September 1992. The main results are the first long-term float trajectories in the tropical Atlantic. New information is revealed about the thermohaline circulation, including a swift southward-flowing DWBC at 1800 m that at times crosses the equator and at other times feeds an eastward equatorial current. The floats give a first Lagrangian view of the deep equatorial current system and its connections to the currents along the western boundary.

A summary plot of the 1800 m trajectories is given in Figure 1. The convoluted pattern of trajectories makes it difficult to see details of the flow along the western boundary. To clarify this a figure showing the swiftest floats (Figure 2) and a schematic summary of float trajectories in the DWBC and near the equator (Figure 3) were drawn. Most 1800 m floats near the western boundary drifted swiftly southeastward in the DWBC paralleling the 2000 m contour. Fastest speeds reached 55 cm/sec in the DWBC near the equator.

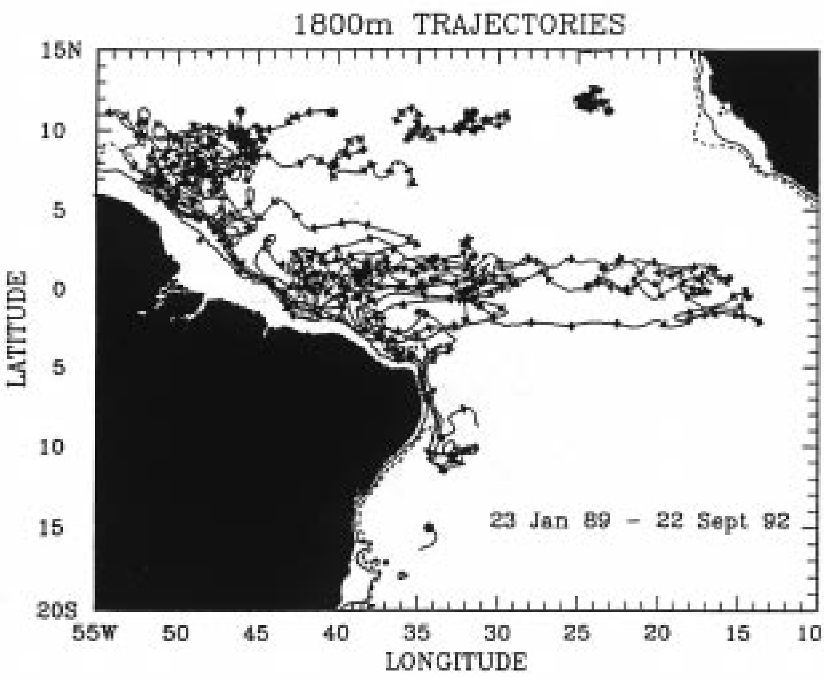

Figure 1. Summary of 1800 m SOFAR float trajectories from January 1989 to September 1992. Arrowheads are spaced at intervals of 30 days along trajectories.

In Figure 3 the high frequency small scale motions have been subjectively removed keeping what is interpreted to be the dominant low frequency large scale motions. In this figure the continuity of the DWBC and its connection to zonal flow near the equator have been emphasized. For clarity, eastward going portions of equatorial trajectories are shown north of the equator and westward going portions south of the equator. The meridional structure shown in the figure is not meant to represent actual meridional structure of the currents which at least in the mid-Atlantic, 10°W–30°W, looks like eastward flow near the equator (1°S–1°N) and westward flow centred near 2°N and 2°S.

Five floats (2, 5, 8, 13, 14) were located in the DWBC near 7°N. Two of these (2, 8) were launched offshore of the DWBC. They drifted westward into the DWBC then southward across the equator reaching 16°S and 11°S. Both of these made small scale recir-

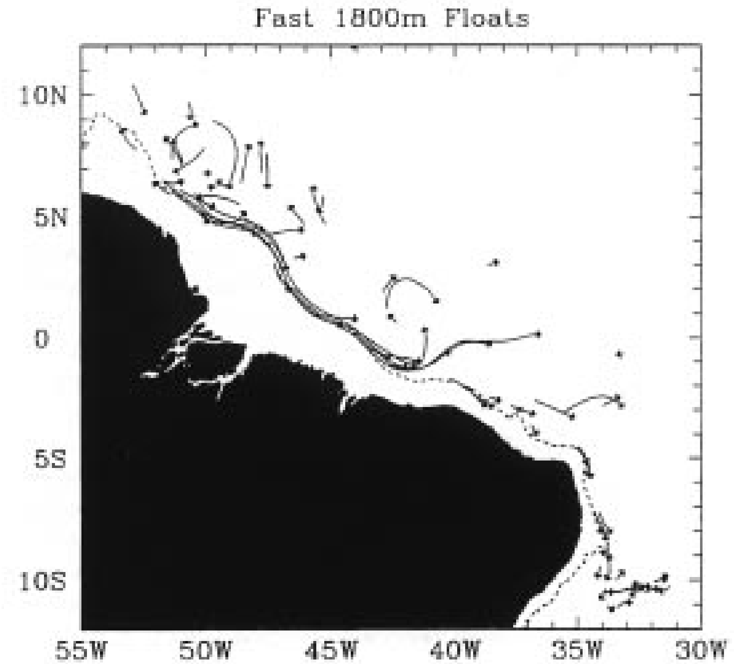

Figure 2. Segments of 1800 m trajectories that drifted faster than 20 cm/sec. Dashed contour is 2000 m. The DWBC is typically 100 km wide and is located adjacent to the continental margin, at least between 7°N and 8.5°S.

culations near the equator. Float 5 drifted southward in the DWBC until reaching the equator where it went eastward ending up near 3°N 32°W. Float 14 drifted southward in the DWBC to the equator, recirculated northward to 9°N and drifted southward in the DWBC a second time ending near 0°N 40°W. Float 13 is a very convoluted trajectory with portions in the DWBC and portions in recirculations some of which were located close to the western boundary. This trajectory which ended near 10°N 52°W was judged too complicated to include in the schematic.

Four floats (1, 6, 9, 15) were launched near the equator in the western Atlantic. Float 1 went eastward along 2°S ending up near 0°N 18°W. Float 6 went eastward along 2°N to 27°W, returned westward along 0°N–1°N, entered the DWBC and went southward past 9°S. Float 9 launched in the DWBC on the equator drifted eastward to 19W, back westward, and then southward along the western boundary to 4°S. Float 15 drifted slowly westward along the equator, then southward along the western boundary, ending at 5°S.

There is good evidence that most of the DWBC water crosses the equator in the west either directly (floats 2 and 8) or indirectly with an eastward diversion along the equator. Floats 1, 5 and 9 show a direct connection between flow in the DWBC north of the equator and flow along the equator. Floats 6, 9 and 15 show that water along the equator can eventually return to the western boundary and go south in the DWBC. Taken together the above two groups of floats imply that DWBC water can go eastward along the equator but that it probably eventually returns westward and continues southward in the DWBC. There is no evidence for continuous eastward flow along the equator to the eastern boundary or for meridional flow outside the DWBC.

Floats 2 and 8 took 14 months and 12 months, respectively, to go from 7°N to 10°S with mean along-boundary velocities of 8.1 cm/sec and 8.6 cm/sec. Values for float 8 were adjusted for the 4.3 months it was aground and slowly (1.5 cm/sec) dragging along the sea floor. The mean along-boundary velocity of float 14 including its two passes down the boundary from roughly 6°N to the equator and its recirculation was 1.1 cm/sec. The mean along-boundary velocity of floats 6 and 9 from their launch locations near the equator to 9°S (float 6) and 4°S (float 9) was 2.5 cm/sec and 0.7 cm/sec respectively. The value for float 6 was adjusted for the 19 months it was aground and stuck near 3°S.

In summary, at times DWBC water can flow directly southward across the equator with a mean velocity of 8–9 cm/sec averaged over long distances (~2800 km). Some DWBC water is recirculated which can reduce its mean along-boundary velocity substantially. At other

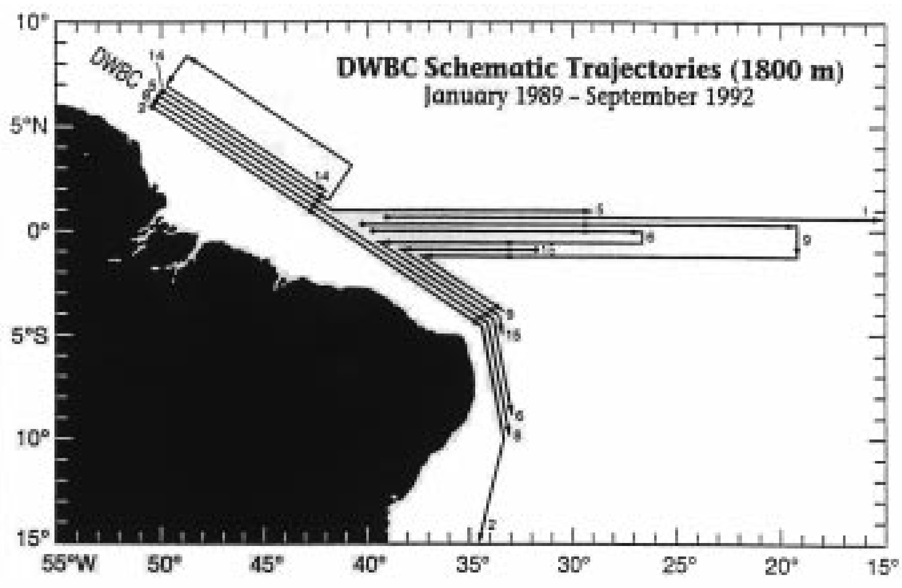

Figure 3. Schematic diagram showing trajectories of 1800 m floats that drifted southward in the deep western boundary current. The trajectories were ordered in distance from the western boundary by how far south the floats ended. The diagram emphasizes the long drifts along the western boundary and along the equator. Small scale motions were subjectively eliminated.

times DWBC water is diverted eastward near the equator for long times – 1.7 years for float 6, 3.3 years for float 9 – which also can reduce the mean along-boundary velocity to 1–2 cm/sec. These mean velocities are considerably smaller than instantaneous along-boundary float velocities which are often above 25 cm/sec and occasionally exceed 50 cm/sec.

All three DWBC floats that went the farthest south diverged away from the western boundary near 8.5°S. This may be partially caused by the orientation of the western boundary which becomes more southwestward there. Float 2 left the boundary and became trapped in a cyclonic eddy near 10°S 32°W for 170 days (Figure 1). The eddy did not move far. After leaving the eddy float 2 continued southward to 16°S although tracking was intermittent because topography blocked the acoustic signals. Float 8 drifted south to 10.5°S and made a partial cyclonic loop around the eddy in which float 2 was trapped. Float 6 went south to 9.5°S then turned and drifted eastward.

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Preliminary Results from "A Mediterranean Undercurrent Seeding Experiment" (AMUSE)

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In 1976, a subsurface, anticyclonic eddy with anomalously warm and saline water was discovered in the western North Atlantic Ocean near the Bahama Islands (McDowell and Rossby, 1978). The core of this lens had T–S characteristics similar to Mediterranean Water some 6000 km away in the eastern North Atlantic, and it was hypothesized that the eddy had formed in the Mediterranean outflow and transported a core of Mediterranean Water across the Atlantic. This Mediterranean eddy, or meddy, as it was called, was able to preserve its Mediterranean characteristics due to its rapid anticyclonic rotation, which dynamically isolated the core from the surrounding water.

This initial discovery prompted a search for meddies closer to their proposed formation region, and in the last decade, many have been found and studied in the eastern North Atlantic. Although some of the general characteristics of meddies have now been fairly well-documented, fundamental questions remain regarding their formation. For example, where do meddies form? What physical process is responsible for their formation? How many meddies are born each year, and how long does it take a meddy to come to life? Studies of meddy population suggest that $^1/_4$ to $^1/_2$ of the salt flux of the Mediterranean Outflow may be carried in meddies (Richardson *et al*., 1991; Arhan *et al*., 1994). Considering these statistics (and their uncertainty), we need to learn more about the life histories of meddies if we are to understand how the distributions of temperature and salinity are maintained in the North Atlantic.

A new experiment, called A Mediterranean Undercurrent Seeding Experiment (AMUSE), is currently underway to identify meddy formation sites, estimate the rate of meddy formation, and identify the pathways of Mediterranean Water <u>not</u> trapped in meddies. The focus of this programme has been the sequential seeding of the Mediterranean Undercurrent south of Portugal (near 36°30'N, 8°30'W, Figure 1) with 40 acoustically-tracked RAFOS floats. The Undercurrent is a wall-bounded jet that carries the outflow from the Strait of Gibraltar around the northern rim of the Gulf of Cadiz. The seeding location was chosen to be upstream of any proposed meddy formation sites, and downstream of the region of sinking and entrainment near the Strait.

The RAFOS floats were launched in pairs from a chartered research vessel on approximately a weekly basis between July 1993 and March 1994. The lower of the two main cores of warm, saline Mediterranean Water that are found in the Undercurrent was tagged with the floats, between 1000 and 1200 m. In order to locate the best float launch sites, an XBT section was made across the Undercurrent on each weekly trip. The positions of the XBT stations at the beginning of the seeding programme

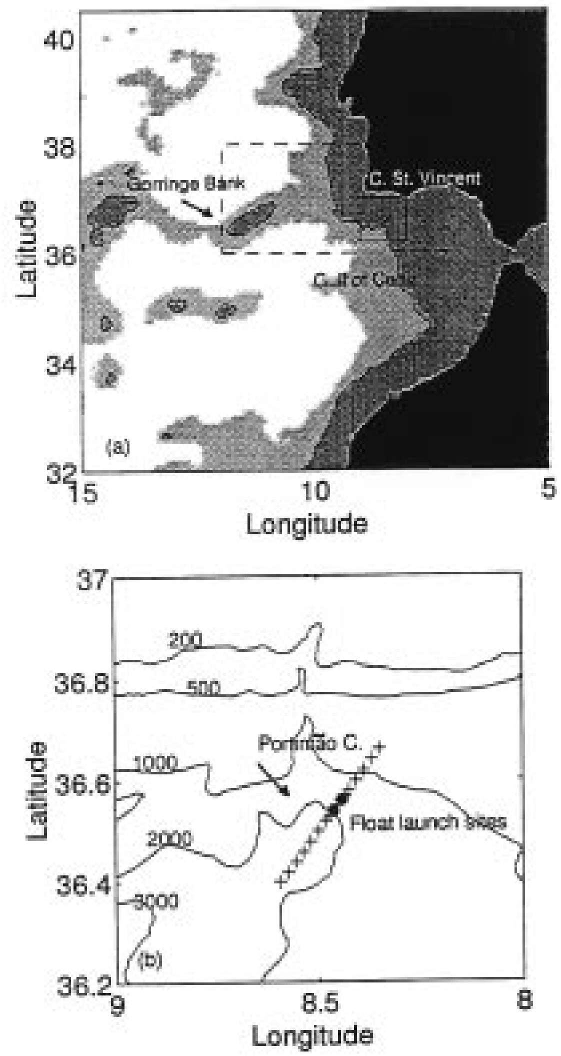

Figure 1. (a) Chart of the eastern North Atlantic showing the Iberian Peninsula, the Strait of Gibraltar and the northwest coast of Africa. The shading indicates water depth in 2000 m intervals, and the 2000 m contour is indicated in black. The small box is expanded in (b) to show the location of the XBT section (+'s) and the approximate float launch sites near Portimão Canyon. The dashed box in (a) is enlarged in the panels of Figure 3.

are shown in Figure 1b. As the programme developed, this line was extended in both directions to encompass the entire Undercurrent. This XBT data will provide a time series of the temperature structure of the Undercurrent during the float seeding.

The XBT temperature section from the first seeding trip on 5 July 1993 is shown in Figure 2. The 12°C isotherm has been highlighted to emphasize the two warm cores, one centred at about 800 m and the other at about 1300 m. Note the rich structure of interleaving of the warm Mediterranean Water and cooler Atlantic waters. Floats 103 and 105 were deployed along this section, and their initial cross-stream position and depth are shown in this figure (see below). After the first few floats had been deployed near 1100 m, the target depth was increased to 1200 m to more closely tag the lower core, while still maintaining a comfortable distance above the ocean bottom.

Most of the floats have been programmed for one-year missions. While underwater, their positions are being fixed three times daily using an array of German, French and US sound sources moored in the Iberian and Canary Basins. The floats also measure temperature and pressure at each position fix. Although most of the floats are still underwater and will not start returning data until June 1994, five 30-day trajectories were obtained in the process of testing the deployment strategy. These trajectories are shown in Figure 3, superimposed on a smoothed version of the bathymetry. The trajectory in each panel connects all the position fixes for each float. Rather than show every position fix along the trajectory, we have shown only the positions where the temperature measured by the float exceeded 12°C. With this presentation format, speed information along the track is lost (except for 103 in Figure 3b, which was warmer than 12°C for its entire mission), but the interesting relationship between the float behaviour and temperature is clearly exposed.

Four of the five tracks indicate strong westward advection from the launch site to Cape St Vincent, at the southwest corner of Portugal. Average speeds in this section were on the order of .25–.30 m s^{-1} , although 103 moved west at about .40 m s^{-1} . Float 116b (Figure 3e) did not take as direct a route as the other four floats, but it

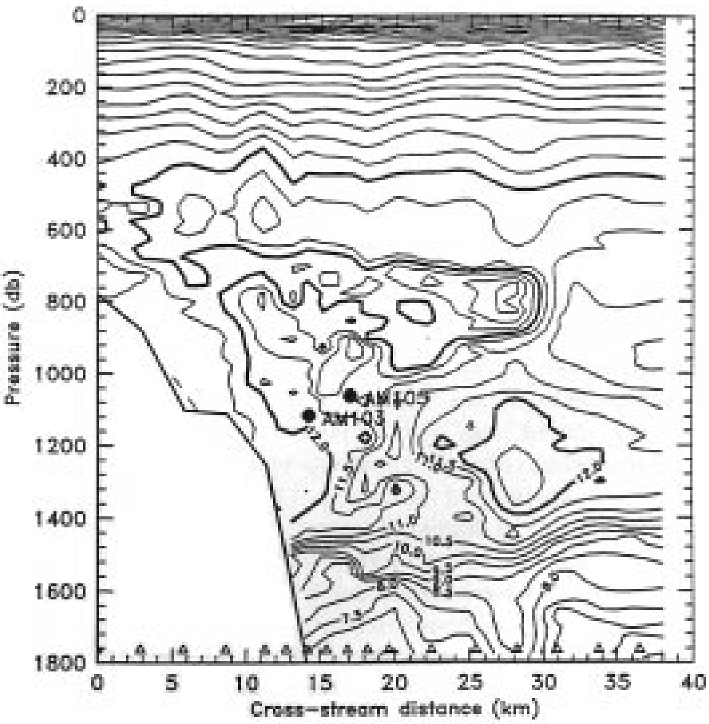

Figure 2. XBT section taken along the line shown in Figure 1b on 5 July 1993. The triangles along the bottom of the figure indicate the locations of the XBT profiles. The 12°C isotherm is darkened. The two solid symbols show the initial cross-stream position and depth of the two floats deployed along this section on the same day.

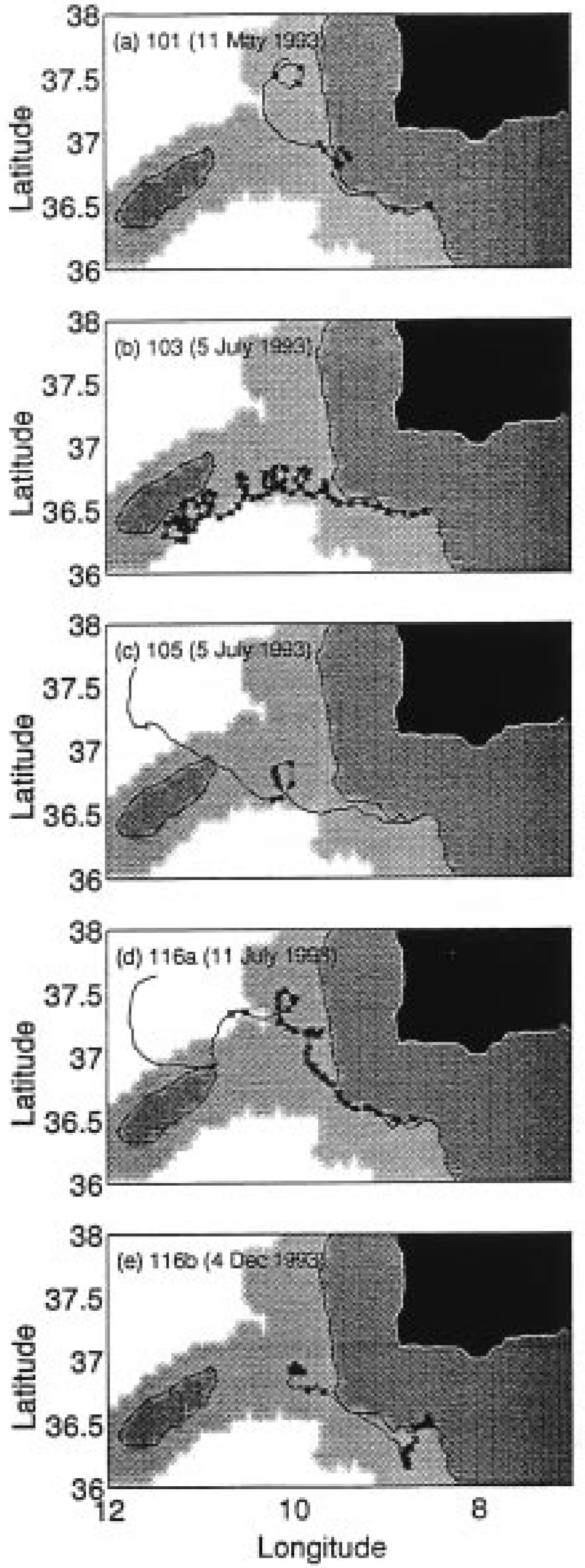

Figure 3. Thirty-day trajectories of five RAFOS floats deployed at the sites shown in Figure 1b. The land is black, outlined in white, and Gorringe Bank is at the bottom left-hand corner in each panel. The float number and date of launch are shown in the upper left-hand corner of each panel. The locations along the tracks where the floats observed a temperature in excess of 12°C are marked by small asterisks. Depth shading is same as in Figure 1a.

eventually reached Cape St Vincent, at which point it stalled until the end of its mission. All five floats indicate a tendency for anticyclonic looping west and southwest of Cape St Vincent. In particular, float 103 (Figure 3b) was trapped in the formation of a new meddy southwest of Cape St Vincent, indicated by the persistent anticyclonic looping and the consistently warm temperature along the track. This is the first direct observation of a formation event. Float 103 looped around the meddy centre at a radius of about 10 km, with azimuthal speeds on the order of .20–.25 m s-1, indicating a rotation period of about 3 days. The relatively high temperatures measured by this float indicate that it was tagging relatively pure outflow water. The other floats consistently measured temperatures greater than 12°C when making anticyclonic loops and/or when they were near the boundary.

Float 105 (Figure 3c) was deployed at the same time as 103, but 3 km farther offshore, in water with temperature less than 12°C. It made one loop around the same meddy that 103 was trapped in, at which point it observed elevated temperatures, but it did not stay trapped with the meddy. Rather it moved off to the northwest, while the meddy translated southwest along the southern flank of Gorringe Bank.

The trajectory of float 103 confirms speculation that Cape St Vincent is one site of meddy formation. As more floats surface, other meddy generation sites may be revealed, and clues about the formation process may become more apparent. The potential role of submarine canyons in the generation of anticyclonic flow is suggested in the trajectory of float 101 (Figure 3a). The loop of this float southwest of Cape St Vincent is located at the entrance to St Vincent Canyon, although the canyon is not resolved by the bathymetric chart shown here. Float 116b (Figure 3e) apparently stalled just offshore of the same canyon entrance. With more trajectories, we will be in a better position to assess the importance of canyons in the generation of meddies.

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The Romanche Fracture Zone:
Blocking and Mixing of Arctic and Antarctic Waters at the Equator

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The Mid-Atlantic Ridge divides the deep water of the Atlantic Ocean into western and eastern components. These deep western and eastern oceans differ substantially from one another to a large extent because Earth's rotation has the effect of guiding newly formed dense water directly from polar regions into western basins, raising circulation rates and renewing tracer fields there. The eastern basins of the Atlantic, by contrast, have weaker mean flows and weaker property gradients, and it is only relatively recently that accurate measurements have allowed circulation patterns to be disclosed (Warren and Speer, 1991; McCartney *et al.*, 1991). The controlling factors are the sill depths of the ridges over which dense bottom water must pass to gain access to the eastern basin and the mixing which occurs at these sills. A longstanding question in oceanography concerns the sill depth of the Mid-Atlantic Ridge at the Romanche and Chain Fractures Zones in the equatorial Atlantic, and the degree of bottom water modification as it flows through this passage. New measurements show a sill depth of 4350 m and a dramatic mixing between bottom water and deep water as bottom water cascades into the eastern basin.

Insufficient bathymetric information has led to estimates (Wüst, 1936; Metcalf *et al.*, 1964) of sill depth in the equatorial region of the Mid-Atlantic Ridge ranging from 4800 m to 3750 m, a span of over 1000 m. The principal reason for this enormous variability is a differing interpretation of the hydrographic structure, especially the increase in temperature from one side to the other. In one limit, any difference between east and west temperature at a given level is taken as an indication that colder, upstream water is simply blocked at that level; in the other limit a sill depth is extrapolated from the upstream depth of the minimum observed bottom temperature on the downstream side of the sill. In fact, the pure blocking limit underestimates the sill depth because some temperature increase is to be expected if there is flow driven by a pressure or density gradient, and some additional increase may be expected owing to mixing between bottom water and overlying warmer water as they cascade together over the sill.

To answer these questions about blocking and mixing at the Mid-Atlantic Ridge, the path taken by bottom water from the Brazil Basin in the west to the Guinea and Sierra Leone Basins in the east through the Romanche and Chain Fracture Zones was charted by a combination of bathymetric and hydrographic measurements from the N.O. Atalante in August 1991.

The dominant bathymetric feature is the Romanche Fracture Zone (Figure 1). The portion mapped in our survey encompasses the Vema Deep at 18–19°W with depth greater than 7000 m, the much shallower sill region from 16°–12°W, and the exit to the Guinea Basin and Sierra Leone Basin to the east. The Chain Fracture Zone to the south is a much smaller structure, associated with a smaller

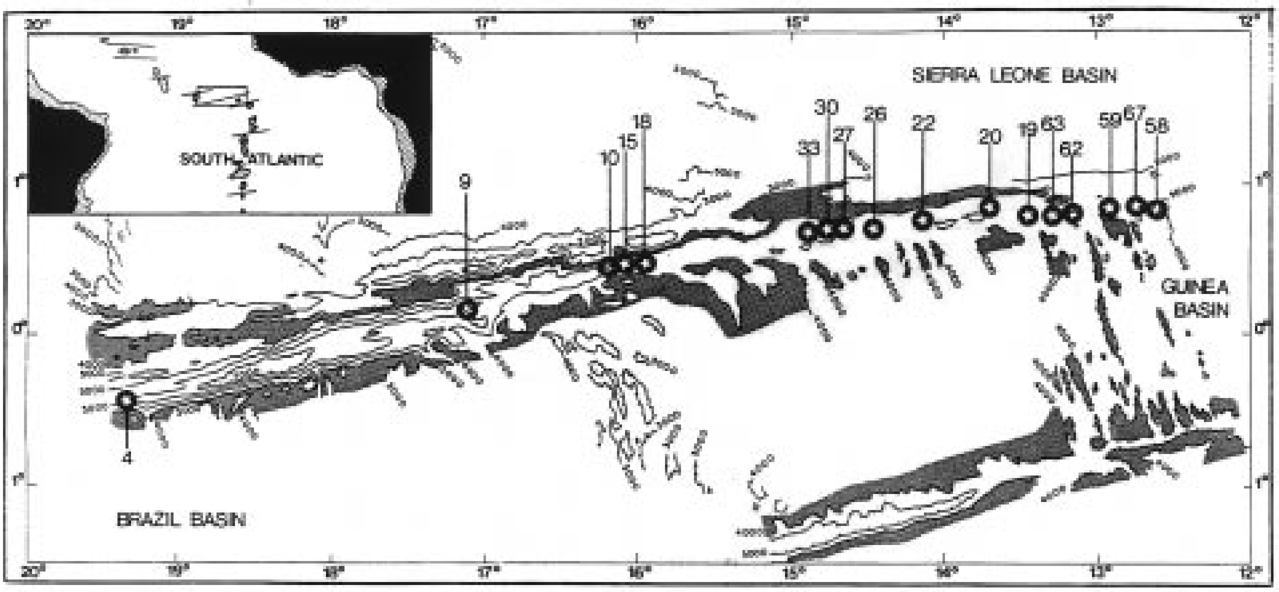

Figure 1. Simplified bathymetry from a multibeam survey of the Romanche Fracture Zone area. Contours every 1000 m; those immediately next to fractures are shaded between 3000 m and 4000 m. Data is missing in large blank areas between fracture zones. Hydrographic stations used to make property sections are marked.

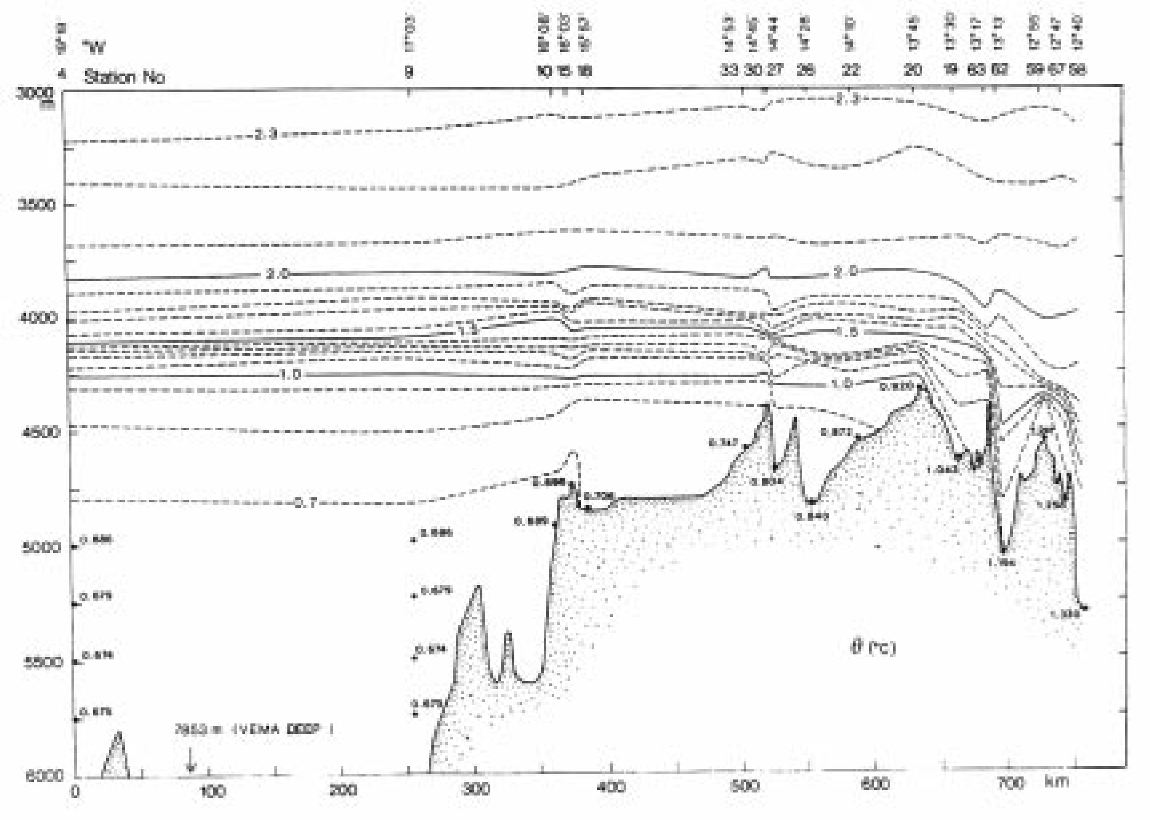

Figure 2. Potential temperature (°C ±0.002) below 3000 m depth along the axis of the Romanche Fracture Zone (see Figure 1 for station positions). Bottom profile represents the deepest point of the fracture; the walls on either side are typically 3000–3500 m deep, so the section is mostly within the fracture zone.

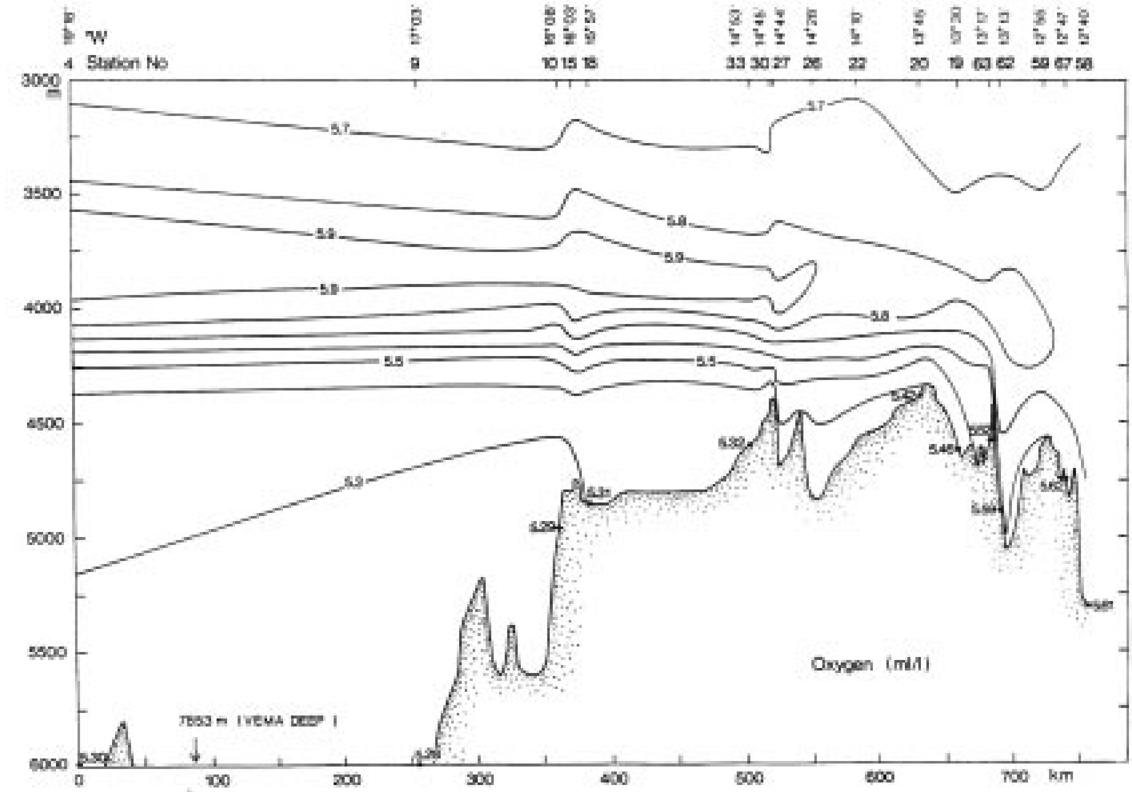

Figure 3. Dissolved oxygen concentration (ml l^{-1} ±0.05) below 3000 m depth along the axis of the Romanche Fracture Zone (as in Figure 2).

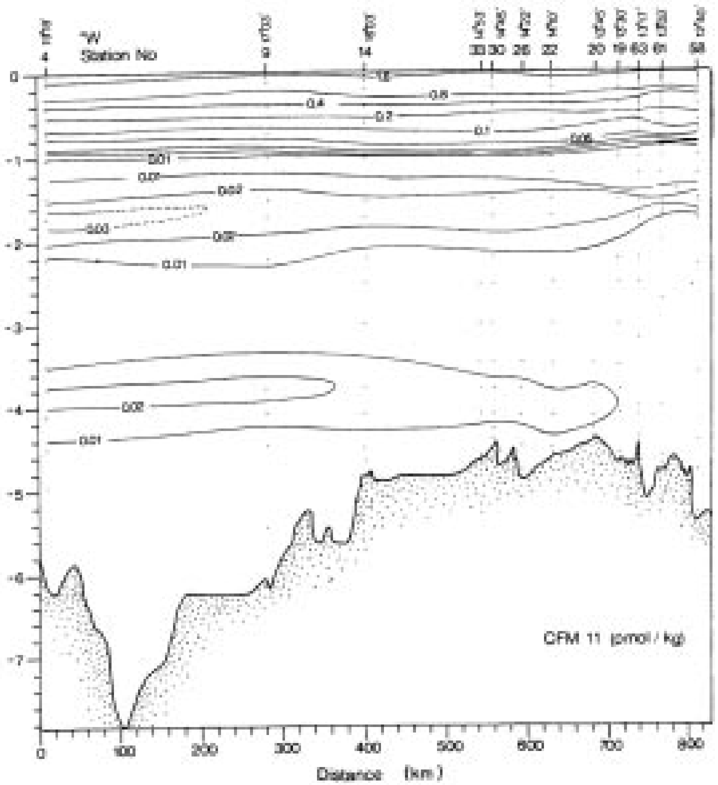

Figure 4. Chlorofluoromethane F-11 (pmol kg^{-1}, ± .005) for the full water column along the axis of the Romanche Fracture Zone. Maxima occur near 1700 m depth (Upper North Atlantic Deep Water) and 4000 m depth (Lower North Atlantic Deep Water).

offset of the ridge. Depths along the axis of the Chain Fracture Zone rise from abyssal plain values of roughly 5000 m to a depth of about 4200 m near 13°W. In between the two fracture zones, the eastern flank of a segment of the Mid-Atlantic Ridge rises to its crest near 16°W.

A subset of the hydrographic data has been used to construct sections of potential temperature (Figure 2), dissolved oxygen (Figure 3), and chlorofluoromethane F-11 (Figure 4) along the axis of the Romanche Fracture Zone. A number of perpendicular sections (not shown) show that all of the variation of properties along the fracture zone is accurately represented by the displayed sections. The fracture zone walls are high enough so that most of the structure below 3000 m lies below them, entirely within the valley formed by the walls on either side.

Projected temperatures lower than 0.7°C occur up to the first significant sill near 16°W or 375 km distance (Figure 2). The coldest water to reach the next sill near 14°45'W is about 0.8°C, then 0.9°C at the sill shortly after, followed by the main sill at 13°45'W with water colder than 1°C crossing it. The main sill depth is 4350 m. Beyond the main sill bottom water falls down toward the exit to the abyssal plain, gaining temperature at every topographic interruption. Isotherm slopes appear to be as sharp as the topography, and the strong temperature (and hence density and pressure) gradients extend upward 500 m or so above the downstream sills. Above that, a weak large-scale doming occurs over the entire sill region.

Antarctic Bottom Water is usually thought of as lying deeper than 4000 m and being colder than 2°C in the Atlantic Ocean, but this definition often includes part of the Lower North Atlantic Deep Water. This North Atlantic component can be distinguished by its higher dissolved oxygen content (Figure 3). A tongue of high oxygen centred at temperatures of 1.9°–2.0°C reaches the sill region from the western boundary (Speer and McCartney, 1991). At the sills, core values decrease by about 0.2 ml l^{-1} over a distance of only 200 km. For a comparable change along the western boundary, the boundary current must cover a distance of several thousands of kilometres. The depth of the oxygen maximum increases across the sill, tracking isotherms as they descend, while the vertical scale or thickness of the high oxygen layer increases roughly by a factor of two. Thus, most of the change in Lower North Atlantic Deep Water characteristics as it flows along the equator occurs abruptly at the sill region.

Full water column chlorofluoromethane measurements were made in the Fracture Zone (Figure 4). These show the tongue of Lower North Atlantic Deep Water near 4000 m depth in a dramatic way, because surrounding unpolluted water has zero concentration. Both the lower tongue near 4000 m depth and the Upper North Atlantic Deep Water tongue near 1700 m have been traced down the western boundary of the Atlantic Ocean from high latitude origins (Fine and Molinari, 1988; Weiss *et al.*, 1985). The measurements reported here are the first sign of the lower F-11 plume extending from the western boundary along the equator and reaching across the sill of the Mid-Atlantic Ridge into the eastern basin. Eventually, the deeper signal ought to extend all along the equator like the upper one does, though an apparently strong vertical mixing may be holding it up temporarily in the sill region. One of the purposes of repeatedly measuring a tracer like freon with no deep background concentration is to improve estimates of vertical mixing over the sills.

A key message in this evolution of properties is the intimate connection between the changes in bottom water and deep water characteristics. In the western basin these are very distinct water masses; in the eastern basin much of their distinctiveness is lost, and a mixture of the two fills the eastern deep Atlantic Ocean up to the Walvis Ridge near 30°S (Warren and Speer, 1991).

A striking feature of the temperature distribution (Figure 2) is the concentration of isotherms between 1°C and 2°C near 4000 m depth. Above and below this level the spacing of isotherms is greater and hence the vertical temperature gradient is weaker. Cold water entering the Brazil Basin in the south would naturally tend to fill the basin, forming a deep thermocline between it and warmer water above at the level at which water leaks out. Except for the Romanche Fracture Zone, the only other sink for bottom water is the Ceara Rise (Whitehead and Worthington, 1982) in the western equatorial region, with a sill depth only 150 m deeper at 4500 m. The water which leaves the basin is warmer than that which enters; the exact temperature of such a deep thermocline would depend on the amount of interior vertical mixing in the Brazil Basin, since this tends to warm bottom water and raise the temperature at the sill. In any case, the present data show that this sill depth control is exerted at a temperature of about 1°C.

Present ocean general circulation models fail to account for the abrupt changes in ocean properties across gaps and passages between ocean basins. It is unlikely that the physics of flow through small-scale passages can be included in practical general circulation models in the near future, making measurements in these locations all the more critical to a proper interpretation of modelling results. One example of the type of measurement to be made is cross-isopycnal diffusion. Simple scaling of the advection-diffusion equation with the observed spatial scales of the fracture zone and horizontal velocities of order 10 cm s^{-1} would lead to estimates of vertical diffusion orders of magnitude greater than typical abyssal values of order 1 $cm^2 s^{-1}$ (Whitehead and Worthington, 1982). Such measurements will eventually allow the effect of passages to be parameterized correctly in large-scale models.

Acknowledgements

We would like to thank the crew of the N.O. Atalante during ROMANCHE 1 for their help in making it successful.

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The North Atlantic Tracer Release Experiment

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The field work for a study of mixing and stirring in the pycnocline of the North Atlantic, begun in 1992, is now nearly completed. The project, dubbed the North Atlantic Tracer Release Experiment, has been a joint effort by the United States, the United Kingdom, and Canada, and has been performed under the auspices of the WOCE programme in those countries. A thin patch of tracer (140 kg of sulphur hexafluoride) was injected in May 1992 on an isopycnal surface at a depth of about 300 m in the pycnocline of the eastern subtropical North Atlantic (Figure 1). This patch was sampled immediately after the injection, again in the fall of 1992, and then in the spring of 1993, as it dispersed. Numerous measurements of the hydrodynamic fields associated with the mixing were made during the experiment to place the tracer observations in dynamical context.

Diapycnal spreading of the patch during the summer of 1992 yielded an excellent measurement of the diapycnal eddy diffusivity (Ledwell et al., 1993). Surveys in the fall of 1992 from RV Oceanus determined this diffusivity to be around 0.1 cm^2/s. These surveys also found the patch, which was originally about 25 km across, to have grown into a sinuous streak hundreds of kilometres long (Figure 2). The width of this streak was on the order of 10 km, indicating a rather efficient mechanism of cross-streak dispersion.

Only about a third of the tracer was found in the fall of 1992, essentially because we had to feel our way along the streak. Most of the general area occupied by the streak was free of tracer. This situation had changed dramatically by the time the CSS Hudson and the RRS Charles Darwin arrived at the site for their simultaneous sampling in mid April 1993. Nearly every cast in an area hundreds of kilometres across came up with at least some tracer (Figure 2). Hudson obtained over 60 vertical profiles from rosette casts that were performed in concert with microstructure profiling by Neil Oakey of Bedford Institute of Oceanography and Barry Ruddick of Dalhousie University. These profiles were mostly concentrated at spacing of

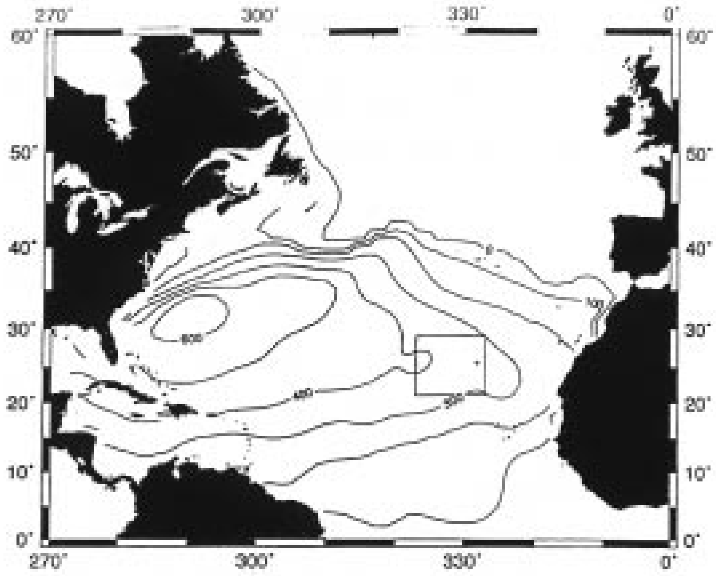

Figure 1. Location of the experiment. The '+' shows the injection area. The rectangle shows the frame of the spring 1993 survey shown in Figure 3. The contours show the depth in metres of the target density surface, defined by a potential density of 1026.75 kg/m^3.

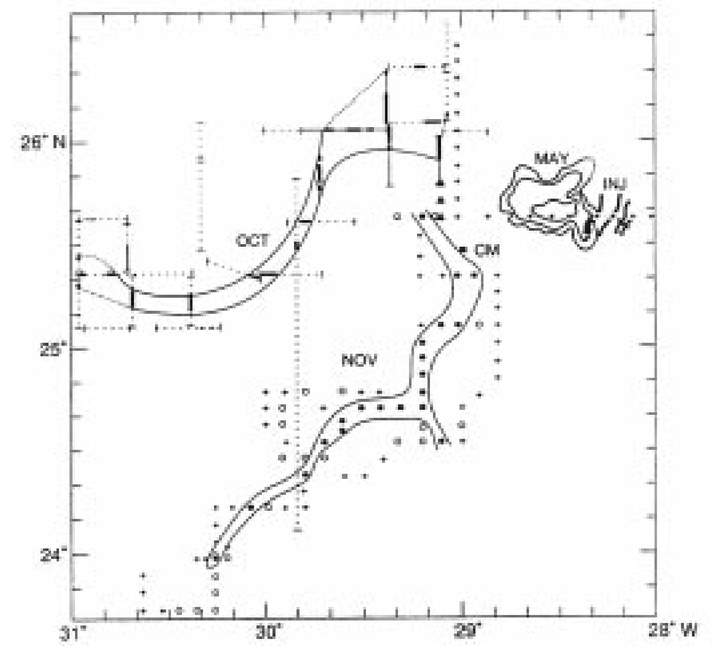

Figure 2. Evolution of the lateral distribution of the tracer. The injection streaks are shown as short heavy lines near 26°N, 28°W. The contours just to the west show the patch later in May 1992. The heavy lines further to the west show tracks for the October 1992 survey where the concentration C at the target surface was greater than 500 fM; the light solid lines show where C was between 100 and 500 fM; and the dashed lines show where C was virtually 0. The solid triangles indicate bottle stations occupied at the end of the October cruise with C > 300 fM. The station symbols for the November survey are '+' for C < 30 fM, 'o' for C = 30 to 300 fM; and '•' for C > 300 fM. A fine curve has been drawn to envelop the high C regions for the two surveys. 'CM' marks the location of the central mooring for the Subduction Experiment. [fM = femtomolar, i.e. 10^{-15} moles/L.]

1 to 10 miles to study the patch at a relatively fine scale.

Darwin, on the other hand, performed a broad survey with over 160 stations spaced approximately 15 miles apart along the ship's track, with 60 miles between legs of the track. This resolution was not sufficient to map the patch accurately, there still being many features at scales of a few kilometres, as in the previous survey. However, two different approaches to integrating the amount of tracer in the patch indicate that virtually all of the tracer was located within the region encompassed by the stations shown in Figure 3.

The filling in of the patch between the fall of 1992 and the spring of 1993 is in marked agreement with predictions by Garrett (1983) and by Haidvogel and Keffer (1984). The idea is that the length of the sinuous streaks grows exponentially with time with something like the rms strain rate of the mesoscale eddies, while the general area occupied by the streaks grows with some low power of time.

The vertical profiles of the tracer distribution (Figure 4) again yielded an accurate measure of the diapycnal diffusivity. The value for the period between the fall of 1992 and the spring of 1993 was closer to 0.2 cm^2/s than to the summer value of 0.1 cm^2/s. It is unlikely that the difference was due to undersampling during the fall survey. There was no indication on this survey of spatial gradients in the diapycnal spread of the patch, and in the spring survey the average of 10 or 20 profiles from almost any corner of the patch would give close to the same answer as the average over the whole patch. Thus, it appears that mixing during the winter months was more vigorous than during the summer.

Various hydrodynamic measurements were made during the experiment. A pair of current meters maintained at 300 m and 310 m depth on the Central Mooring of the Subduction Experiment from February 1992 to June 1993 show that the internal wave kinetic energy and shear during the experiment were fairly typical of the open ocean at the ambient stratification. Microstructure measurements during the experiment from a variety of platforms suggest that dissipation rates were consistent with the diffusivities measured by the tracer (Schmitt, Polzin, and Toole, 1994; Oakey and Ruddick, 1994; Duda and Jacobs, 1994; and Sherman and Davis, 1994). Trajectories from SOFAR floats launched with the tracer by Jim Price and Phil Richardson of WHOI will yield Lagrangian statistics on the eddy field responsible for the lateral dispersion. All of these data will provide the context of the mixing, and will enable tests of formulas which have been proposed to estimate diapycnal and isopycnal mixing.

It is interesting to consider the course of the tracer patch over the next few years. The prevailing currents would bring the patch toward the west, with the leading edge reaching the outer Antilles Islands perhaps in 1996. A cruise is scheduled to sample the patch at least once more, in September 1994, to determine the diapycnal and lateral dispersion, and the lateral homogenization that has occurred over the last year.

The experiment is supported by the National Science Foundation and the Office of Naval Research in the US, by the Natural Environment Research Council in the UK, and by National Sciences and Engineering Research Council and the Bedford Institute of Oceanography of Canada. Thanks are due to the crews of the ships involved, and to our home institutions.

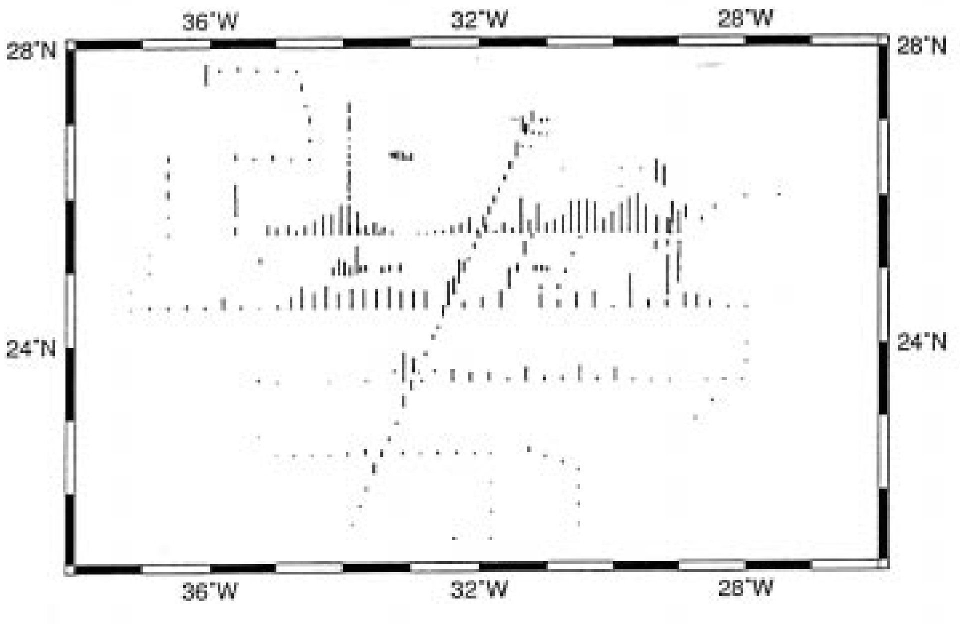

Figure 3. Tracer Survey – Spring 1993. The base of the vertical line segments show the station locations and the height shows the relative amount of tracer found. The injection area was at the northeast extremity of this survey.

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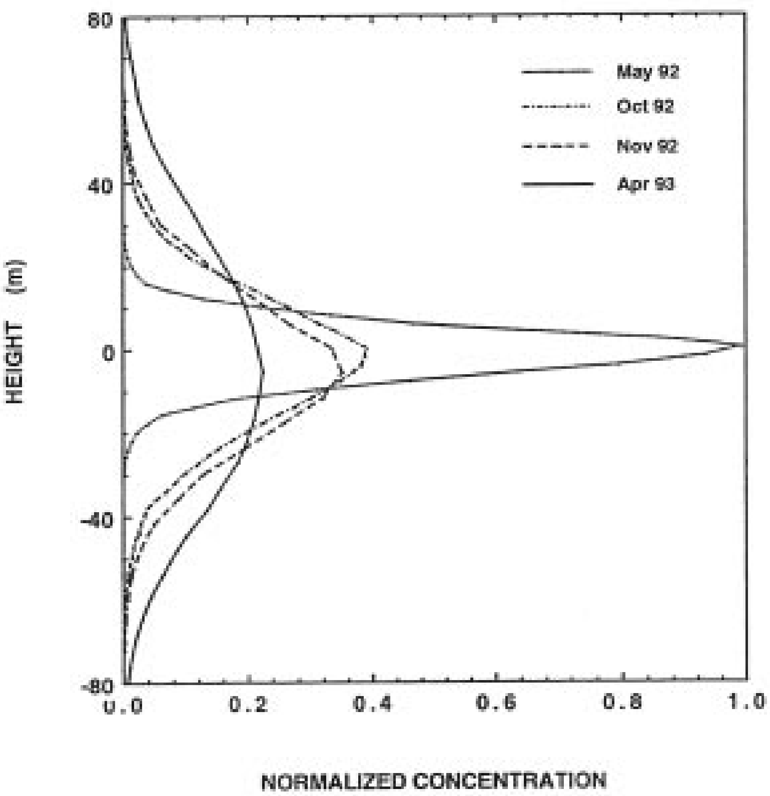

Figure 4. Vertical spreading of the patch. Each curve is the mean of all the profiles from a cruise. The growth with time of the second moment gives estimates of the diapycnal diffusivity. The area under each curve is the same.

FS Meteor Completes A8

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A8 was the last of three zonal WHP sections in the South Atlantic as part of the German WOCE contribution: Sections A9 (19°S) and A10 (30°S) were completed on Meteor cruises 15/3 in 1991 and 22/5 in 1993, respectively. On A8, 110 full depth stations with CTD and up to 40 bottle samples per station were obtained. Water samples were analysed onboard for salinity, oxygen, nutrients, anthropogenic tracers CFC-11, CFC-12, CFC-113, CCL4 and carbon dioxide. In addition, underway measurements of currents and meteorological data as well as near surface temperature and salinity were made.

During the cruise the nominal station spacing was decreased to 10 nm and 5 nm over the shelf and continental breaks, to 24 nm over the mid Atlantic Ridge, and increased to 38 nm over the deep Pernambuco and Angola basins. Bottle samples to analyse for oxygen, nutrients and salinity were taken on each station, samples for anthropogenic tracers and CO_2 on each second station.

In addition, four test stations and a survey with ADCP were performed off the Brazilian shelf before the WHP section began, and a box around the eastern end of the section was occupied.

Underway measurements of currents were made with a shipborne Acoustic Doppler Current Profiler (ADCP) down to 200 m and with a Geomagnetic Electro-Kinetograph (GEK), eight satellite-tracked drifting buoys and expendable current profilers (XCPs) as well as near surface temperature and salinity and meteorological parameters supplemented the station work.

The cruise also presented the opportunity for non-WOCE measurements. As part of a long-term Atlantic-wide survey of the distribution and ecology of fish larvae, 69 plankton hauls were performed at 6 levels between the surface to 200 m.

Aerosols determine the formation of clouds. Over the South Atlantic several sources may be expected; aerosols of sea salt and remainders of continental aerosols of mostly desert origin as well as particles which result from decomposition of dimethyl sulphide (DMS) formed by chlorophyll in the sea. Aerosol samples were filtered from air and are to be correlated with DMS concentrations in sea water and air.

Meteor sailed from Recife, Brazil, 29 March. Heading eastwards (Figure 1), outside the 12 nm zone at 8°17'S, 34°30'W the continuously recording systems were switched on; the integrated system DVS to acquire navigational and meteorological data as well as near surface temperature and salinity, the shipborne 150 KHz ADCP, and the towed GEK. (DVS is a German acronym for a data distributing system on-board FS Meteor.) The first two days of the cruise were used to test the two CTD systems, each equipped with a 24 x 10 l rosette sampler, on four deep water stations (165–168). Also, the analysis systems for oxygen, nutrients, CFCs and CO_2 were set up.

At 11°20'S, 34°W we began a section along A8 shorewards with XBT and XCP drops thereby achieving a box with ADCP and GEK in the divergence zone of the western branch of the South Equatorial Current.

On 1 April, (Station 169) section A8 started at 10°3'S, 35°46'W on the 200 m depth contour outside the 12 nm zone of Brazil normal to the continental shelf break. On each of the following stations, together with the first CTD rosette, a 150 kHz self-containing ADCP was lowered (LADCP) to 1000 m. The bottles were used to increase the number of water samples up to 40, the bulk of them came from the main CTD lowering which always went down to 10 m above the bottom. At 34°W (Station 181) the nominal latitude 11°20'S was reached, 13 stations at 5 nm to 20 nm spacing were obtained. Station spacing was then increased to 30 nm until 32°W (Station 185).

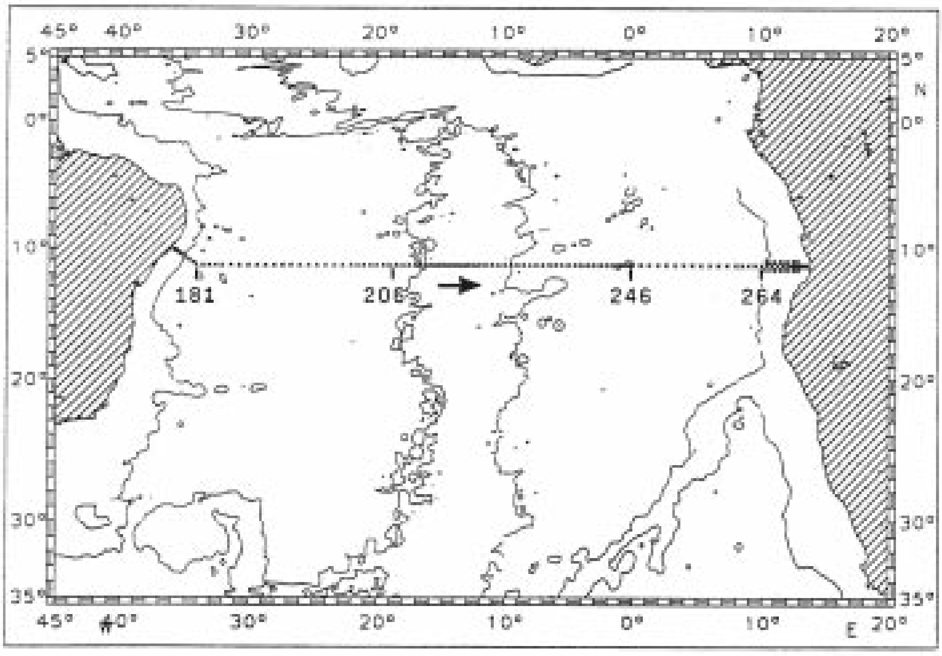

Figure 1. CTD stations during M28/1.

Investigators responsible for WHP underway measurements

CTD, XBT, XCP, ADCP, underway	Thomas Müller, IfM Kiel
Oxygen, Nutrients	David Hydes, IOSDL, UK
Tracers	Alfred Putzka, University of Bremen
CO_2	Kenneth Johnson, BNL Brookhaven

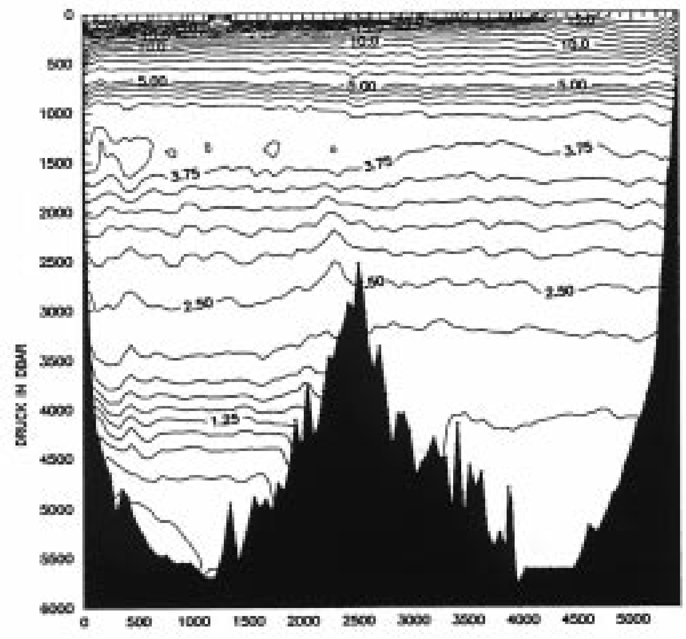

Figure 2. Distribution of potential temperature along 11°20'S from Brazil (left) to Angola (right). Contour intervals are 1°C and 0.25°C for temperatures higher and less 5°C, respectively.

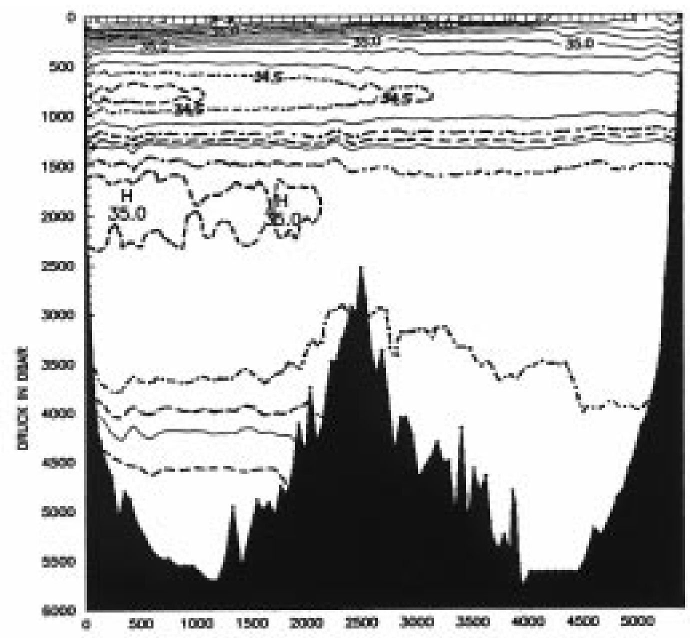

Figure 3. As Figure 2 for salinity. Contour intervals are 0.2 psu between drawn lines. Dash-dot lines denote a controur increment of 0.1 psu, while long dashes resolve the distribution of an additional interval of 0.05 psu.

Here, outside the 200 nm economic zone of Brazil, measurements with the multibeam echosounding system HYDROSWEEP and sampling of aerosols began. Across the Pernambuco Basin, station spacing was increased to 38 nm with T5 (1800 m) XBTs halfway in between. Up to Station 190 at 25°20'W, all stations had biological sampling. From then on spacing for biological hauls was 70 to 90 nm. Four satellite-tracked drifters were launched between 20°W and 15°45'W.

Approaching the mid Atlantic Ridge, from 22°W (Station 200) spacing was decreased to 30 nm to 17°W (Station 210) and down to 24 nm over the ridge to 12°W (Station 222). At 19°S (Station 206) over the western flank of the ridge, we crossed section A15 which was worked at almost the same time by the US RV Knorr. CTD and bottle data from this station were exchanged by e-mail while still at sea.

Spacing was increased again towards the Angola Basin to 28 nm until 1°W where the section ran close to the Dampier Seamount. Expecting higher hydrographic variability and different species of fish larvae, two extra CTD stations (245 and 247, no bottles) and plankton hauls were obtained.

From 0°E onwards station spacing increased to 38 nm across the Angola Basin until we reached the African continental break at 8°E (Station 260). T5 XBT probes were launched halfway between stations. Four more satellite-tracked drifting buoys were launched between 1°20'E and 5°20'E.

With 28 nm station spacing we reached 10°E (Station 264) where we entered the 200 nm economic zone of Angola. Since no clearance had been applied for plankton hauls and GEK, we continued with CTD measurements only. Station spacing was reduced successively to 25 nm and 10 nm until we reached the 50 nm zone at 12°57'E (Station 274). While waiting for an extension of the clearance to 12 nm to be arranged by the German Embassy in Luanda, Angola, we surveyed the northern part of a box around the eastern end of A8 using the CTD/LADCP system down to 1000 m depth (Stations 275–281 along 11°S). We completed this box with stations 282–286 along 11°40'S with plankton hauls as well after the extension of the clearance had been granted. After two days interruption we rejoined A8 at 13°5'E (Station 287) and completed it on the 200 m depth contour at 13°33'E with Station 290 on 7 May 1994.

All deep casts were taken with the same Mk IIIB CTD which already served on A9 and A10. The shallow CTD casts served for calibration purposes and provided CTD values at bottle depths. Figures 2 and 3 display the distribution of potential temperature and salinity using the pre-cruise calibration along A8. Note that salinity is high or low by 0.01 psu and will be adjusted during the final *in-situ* calibration procedure.

Nutrients and dissolved oxygen were measured from each bottle for each station, tracer, pCO_2 and TCO_2 concentrations were determined for each bottle over the continental break and for each bottle taken at alternative stations.

All Current Meters Recovered from the Hunter Channel Array: FS Meteor Finishes Third DBE Cruise

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In Walfish Bay, Namibia, I took over the Meteor from my colleague Thomas J. Müller, who just had completed WHP section A8 along 11°20'S with his team. Initiated by a press release issued by the Coordinator's office in Kiel and the German Embassy in Windhoek, the arrival of the Meteor was well received in Namibia. The town and harbour of Walfish Bay had been peacefully incorporated by the Republic of Namibia only 74 days earlier. Surprisingly many German speaking Namibians from the nearby towns of Swakopmund and Walfish Bay, as well as from the capital Windhoek had come to visit the Meteor. Among them were a few elderly guests who enthusiastically reported their unforgotten impressions of the old Meteor they had visited as school kids some 68 years ago. At that time Kapitän Fritz Spiess was the chief scientist of the legendary Deutsche Atlantische Expedition 1925–27. Our port call at Walfish Bay exceeded everybody's expectation.

The Meteor left Namibia early on 15 May 1994 and sailed directly towards point "A" at 21°S, 10°W, situated on the eastern flank of the Mid Atlantic Ridge. Until early February 1994 we had planned to reach "A" coming from Pointe Noire, Republic of Congo, passing the island of St Helena. However, due to official travel warnings from the US Secretary of State and the German Auswärtiges Amt we were forced to reorganize the cruise track at short notice. The cruise track is shown in Figure 1a.

On 21 May, the Meteor crossed the Mid Atlantic Ridge and occupied her first stations in the eastern Brazil Basin. By then, all continuously recording systems, *i.e.* GEK (Geomagnetic Electro-Kinetograph), ADCP (Acoustic Doppler Current Profiler), radiation and environmental chemistry loggers, had become fully operational and remained so for most of the expedition. The first surface drifters and RAFOS floats were launched at the corner Sta. 295. All drifters were equipped with drogues at a depth of 100 metres. The course then changed southwestward to 223 degrees.

Further CTD stations partly in combination with minicorer deployments, more float and drifter deployments and zodiac based chemical sampling followed until we reached mooring "R", at Sta. 305 on the eastern flank of the Rio Grande Rise on 25 May. This and other moorings had been deployed by the Meteor in mid December 1992 as the German component of the Deep Basin Experiment.

On 27 May we reached the western side of the 200 km-wide zonal cross-Hunter Channel array at moorings "H1-6" (Figure 1b). Favoured by excellent weather conditions all moorings were recovered (Sta. 309–319, 27–30 May) after a 17 month deployment. We used the remaining time in the region for HYDROSWEEP surveys (swath echo sounder) and GEK tracks at night. The systematic survey of the bottom topography of the Hunter Channel is a long-term project of the Alfred-Wegener-Institut, Bremerhaven, the Universität Bremen and the Institut für Meereskunde in Kiel.

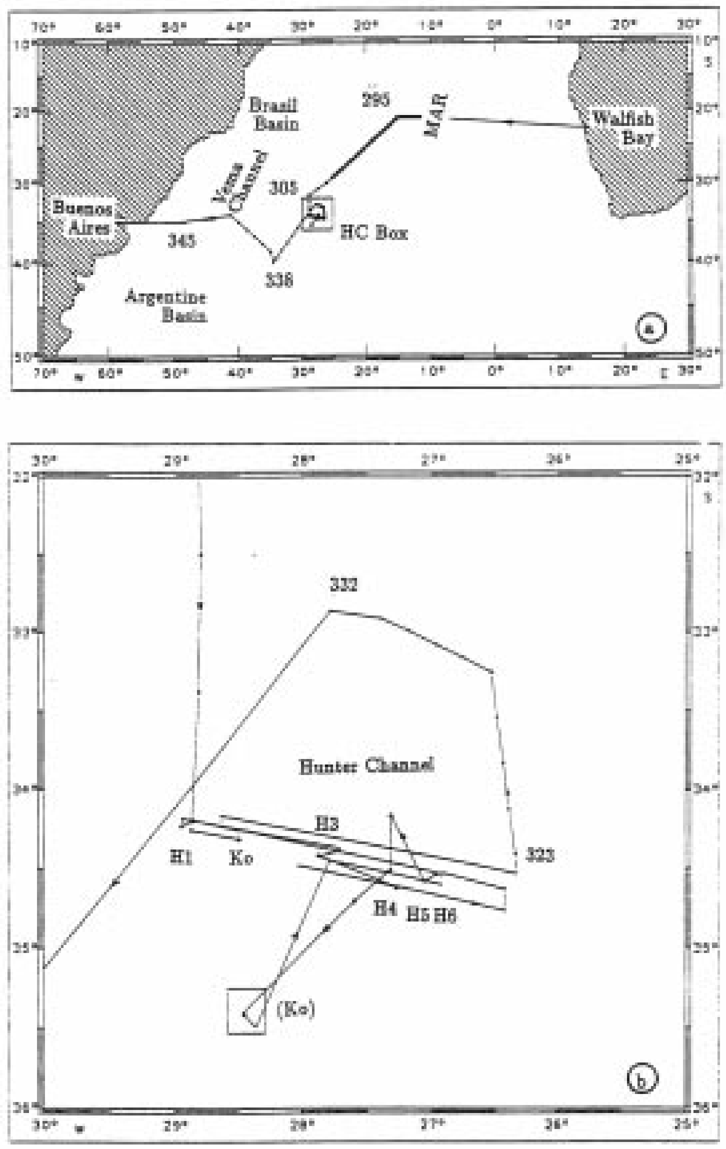

Figure 1. (a) Track of the Meteor cruise No. 28, leg 2. (b) Intensive CTD and mooring work together with nightly bathymetric surveys supplemented the efforts in the Hunter Channel (HC) area where the Meteor spent almost one week.

Analysis of selected CTD stations in conjunction with minicorer deployments will allow more precise hydrographic and sedimentological descriptions of this important passage for Antarctic Bottom Water on its equatorward drift. Figure 2a shows daily averaged vectors of a 17 month-long time series of near bottom flow at mooring "H6". Figure 2b shows a preliminary progressive vector diagram from the near bottom current (15 m bottom clearance) demonstrating the quasi-permanent nature of the overflow through the eastern side of Hunter Channel (34°32.6'S, 26°58.5'W, depth 4303 m). These new results compare well with earlier observations in the Vema Channel.

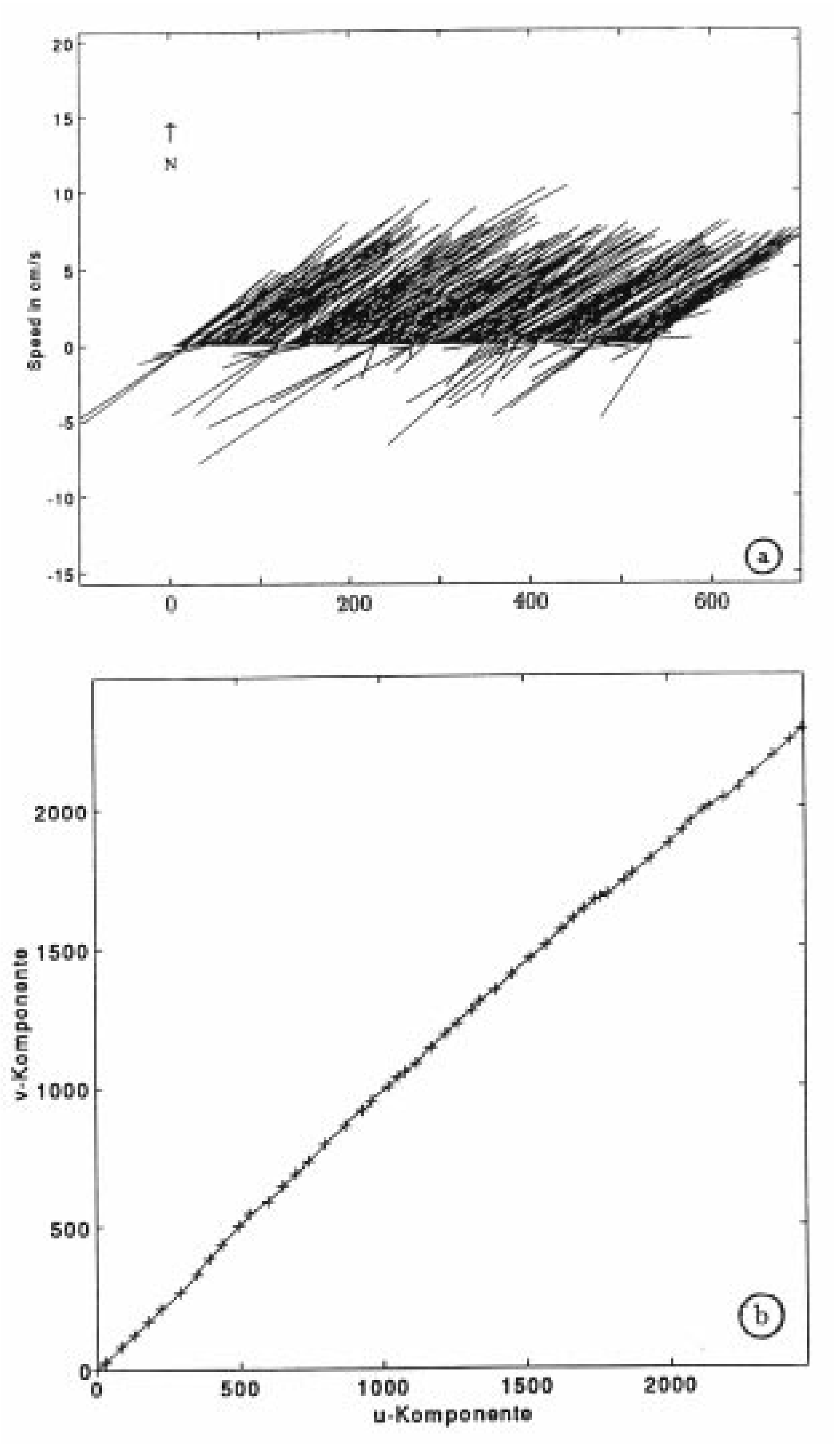

Figure 2. Direct current observations from the eastern sill of the Hunter Channel (Mooring"H6", 15 m bottom clearance). (a) Daily averaged vectors (2 h sampling interval) of the 17 month long record (December 1992–June 1994). (b) Progressive vector diagram of time series in (a). Similar currents were observed at the western sill ("H1").

We expected serious problems with mooring "K0". This sound source rig had broken loose in mid February 1994 when signals from our "watch dog" top buoy were reported by Service ARGOS. Upon several release commands no remainders showed up at the mooring site of "K0" in the Hunter Channel. However, to our greatest surprise we were able to locate the sound source’s shifted position at approximately 35°22'S, 28°28'W by listening with two separate MAFOS monitors on the hydrographic wire. The listening procedure was repeated five nights from different locations resulting in a search radius of less than 8 nm. However, despite of a 36 hour intensive search the Meteor was unable to find the lost mooring on the sea surface. Instead, we spotted two fisherman's balls, one styrofoam plate and a plastic bottle at this location.

On 1 June the search was discontinued. The ship returned to the Hunter Channel and set the replacement sound source mooring "K0 2" (Sta. 322). After a final HYDROSWEEP leg across the Hunter Channel a narrowly spaced deep CTD section was carried out at the eastern and northern exits of the channel area (Sta. 323–332). Because of rough weather conditions we had to skip further minicorer deployments, which were otherwise performed regularly under the CTD probe on deep stations. Chemical samples from the surface (Universität Ulm) were taken regularly from the zodiac during CTD operations whenever the weather conditions allowed.

On 4 June the Meteor left the well measured Hunter region and headed for its southernmost position at 40°S, 35°W. Here sound source mooring "K4" was launched at Sta. 338. Sound sources are an integral component of the RAFOS system. Their signals are sensed by drifting floats. Arrival times of the coded transmissions are recorded in the floats. After the floats surface, typically after 10–15 months, the stored information is transmitted by a satellite link and converted in Kiel into a series of float positions.

The passage towards "K4" was combined with more float and drifter launches and GEK observations, resulting in a quasi-continuous section from the centre (21°S) of the subtropical gyre to its southern perimeter north of the confluence region (35°S).

On station 338 an extended CTD cast was taken. Samples include, as in other selected cases, probes of helium, tritium, nutrients (Universität Bremen) and sulphur hexafluoride (Woods Hole Oceanographic Institution). After the Meteor had occupied this southern corner station she cruised northwestward towards the outer Vema Channel. Additional drifters and floats were launched between shallow (1500 m) CTD-Stations 338 and 344.

After the last drifter and float were deployed on Sta. 342 and 343, respectively, the ship cruised to the final position at the 200 nm-zone off the Brazilian coast line. Here, at Sta. 345 more water samples were taken in the western boundary current system before the Meteor called at Buenos Aires on 14 June 1994.

When approaching the South American shelf the Meteor had occupied 44 CTD stations, 23 of which included joint minicorer deployments. 89 XBT probes were dropped and seven moorings had been recovered and two deployed. 29 RAFOS floats, two MAFOS monitors and 20 satellite tracked surface drifters with drogues at 100 m depth had been launched. Quasi-continuous measurements of solar radiation and skin sea surface temperatures (University of Colorado) as well as nearly uninterrupted GEK records (Institut für Angewändte Physik, Universität Kiel) were collected.

Acknowledgements for Meteor Cruises

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Indian Ocean Plans Continue to Evolve

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The next two years will see the emphasis of the WOCE Global survey shift to the Indian Ocean. The planned programme is the culmination of three years work by US and other investigators, and will continue until 1996, as shown in Table 1. However it is not the first WOCE work in the Indian Ocean; Australian, British, French, and German researchers have all been and will continue to be active in the region. A list of known WOCE and WOCE-related programmes is given in Table 2 and shown in Figure 1.

The US will be responsible for most of the one-time hydrography, but considerable effort has been made to ensure that other nations' work is coordinated. Thus, the British and Australians will be sampling within the ACC at the same time as the US samples I8S and I9S. Section S4 between 20°E and 120°E does not form part of the US expedition, but has been proposed separately for the 1995/96 austral summer. Of the lines originally proposed for the Indian Ocean, only I5 remains uncommitted; the French intend proposing an occupation of the complete line in 1996, which will mean both end sections are occupied twice.

Repeat hydrography is not as well-covered as required by the international WOCE plan. German and Australian scientists have worked in the Arabian Sea and south of Sri Lanka. Three more cruises along portions of IRl and IR3 are planned for 1996 on the Meteor. The Australians will carry out repeat hydrography near Sri Lanka and in the North Australian Basin. Further work in the Perth Basin

Table 1. Latest cruise schedule for US WOCE work in the Indian Ocean (supplied by D. Moller, WHOI)

Legs	Ports	Dates (1994– 1995)	PI
Transit	Brindisi– Fremantle	29 September– 25 October 1994	
I8S, I9S	Fremantle– Fremantle	1 December– 19 January 1995	McCartney
19N	Fremantle– Colombo	24 January– 6 March	Gordon
I8N, I5E	Colombo– Fremantle	10 March– 16 April	Talley
I3	Fremantle– Port Louis	20 April– 7 June	Nowlin
I5W, I4	Port Louis– Port Louis	11 June– 11 July	Toole
I7N	Port Louis– Mattrah	15 July– 24 August	Olson
I1	Mattrah– Singapore	29 August– 18 October	Morrison
Service	Singapore	20 October– 4 November	
I10	Singapore– Singapore	6 November– 24 November	Bray
I2	Singapore– Mombasa	28 November– 19 January 1996	Johnson

Table 2. Known WOCE and WOCE-related work in Indian Ocean (updated 06.22.94)

Year	Month	Knorr	Thompson	Baldridge	Australia	France	Germany	UK
		WOCE	JGOFS/ONR	NOAA				
1989	August					I1		
1991						Start of KERFIX	IR4	
							ICM8 deployed	
1992	March					I10		
1993	January/February					Kerguelen WHP		
	February/March					I6S		ADOX deployed
	April/May							SWINDEX deployed
	July/August				ASEAN		IR4, ICM8	
	August						IR1	
	August/September				I8N			
	September/October				SeaSoar			
1994	February/March							ADOX recovery
	June				ASEAN	End of KERFIX		
	September				SeaSoar, ICM6			
	October				ICM8		ICM8	
	November				WHP S of Australia			
	December	I8S/I9S	ONR					
1995	January	I8S/I9S	JGOFS		S4E			I6/SWINDEX
	February	I9N						
	March	I8N/I5E	JGOFS				IR1W/IR3N	
	April	15E/I3		I1	IR6		ICM7	ICM1
	May	I3/ICM3		I7				
	June	I5W/I4	ONR		Perth Basin		IR1W/IR3N	
	July	17N	JGOFS					
	August	I7N	JGOFS				IR1W/IR3N	
	September	I1	ONR	I8N	IR6			
	October	I1						
	November	I10						
	December	I2	JGOFS					
1996	January	I2 finishes				I7S, Kerguelen		
	January/March	S4						
	Dates unknown				Perth Basin	I5, I6		
					ICM9E			

will occur at a later date. The French time-series station off Kerguelen has now finished after three years.

One of the sampling problems of the northern Indian Ocean is the dramatic change in current patterns between the SW and NE monsoons. Cooperation with other programmes has ensured that at least the Arabian Sea will be well-sampled. In addition to the German repeat hydrography, JGOFS will be taking full-depth water samples close to I7N during five cruises in 1995. Further JGOFS work will be performed by British, German, and Indian researchers. Also, a NOAA-funded expedition will occupy I1W, I7N, and I8N in contrasting seasons to US WOCE work.

Because of the paucity of repeat hydrography measurements, VOS data will provide the main information on the variability of the thermohaline structure of the upper layers. VOS lines known to be operating in the Indian Ocean in 1993 and 1994 include IX1, IX2, IX3, IX6, IX7, IX9N, IX10, IX12, IX15, IX21, IX22, and IX25. Line IX8 appears to be operating only infrequently. Lines IX1 (Australia–Indonesia), IX3 (Mauritius–Red Sea), IX6 (Mauritius–Singapore), IX10 (Singapore–Red Sea), and IX12 (Fremantle–Red Sea) have been recommended by WOCE as high-density lines. The Australians will operate IX1 at high density. Potential exists within the US to begin high-density mode sampling on lines IX15 and IX21. No other high-density lines are committed at this time. (See WOCE Report No.119/94, Summary and Assessment of Resource Commitments for locations of all XBT lines.)

Of the moorings originally planned for WOCE, ICM2 (off SW Australia), ICM5 (in the Mozambique Channel), and ICM9W (on the equator) are unlikely to be occupied. ICM4 in the Indonesian throughflow will probably be completed by various arrays deployed by Australian, French, and US investigators in some of the inter-island passages and south of Java. Otherwise, all moorings will be completed as per Table 2. An additional mooring array, labelled ICM10 in Figure 1, has been proposed by US researchers at the mouth of the Red Sea. The JGOFS/ONR work in the Arabian Sea will support a surface mooring, equipped for both meteorological and subsurface work, over the period from October 1994–January 1996. Additional air-sea flux work has been carried out in the eastern tropical Indian Ocean by US, Australian, and German scientists. This may continue as CLIVAR begins.

The other components of the global programme comprise subsurface floats, surface drifters, and sea level gauges. The float programme will provide a five-year estimate of known motion at approximately 1000-m depth, against which the geostrophic transport may be referenced. US funds are available to provide all the float requirements (180) in the Indian Ocean, plus additional instruments in the Southern Ocean sector.

The drifters will provide surface velocity measurements, and with altimetry data will provide information on eddy frequency and velocity. The US will support 210 drifters. Other than the US, the only known participants in the drifter programme are the Japanese, who have been releasing eight drifters per year in the eastern Indian Ocean since 1990, and the Germans, who plan to release a small number in the Arabian Sea. The Indians have recently purchased five Lagrangian drifters for use in the Arabian Sea, but the scale and duration of this work is unknown.

Sea level gauges have been established throughout the Indian Ocean during various programmes. During the WOCE work they will provide data to calibrate altimeter retrievals from satellites as well as information on large-scale sea surface variability.

In addition, there are several modelling projects on the Indian Ocean, either alone or as part of global models, that may serve to tie together the field data. Because of the very large seasonal and annual changes that occur in this region, modeling is the only way to meld data from different areas and different times.

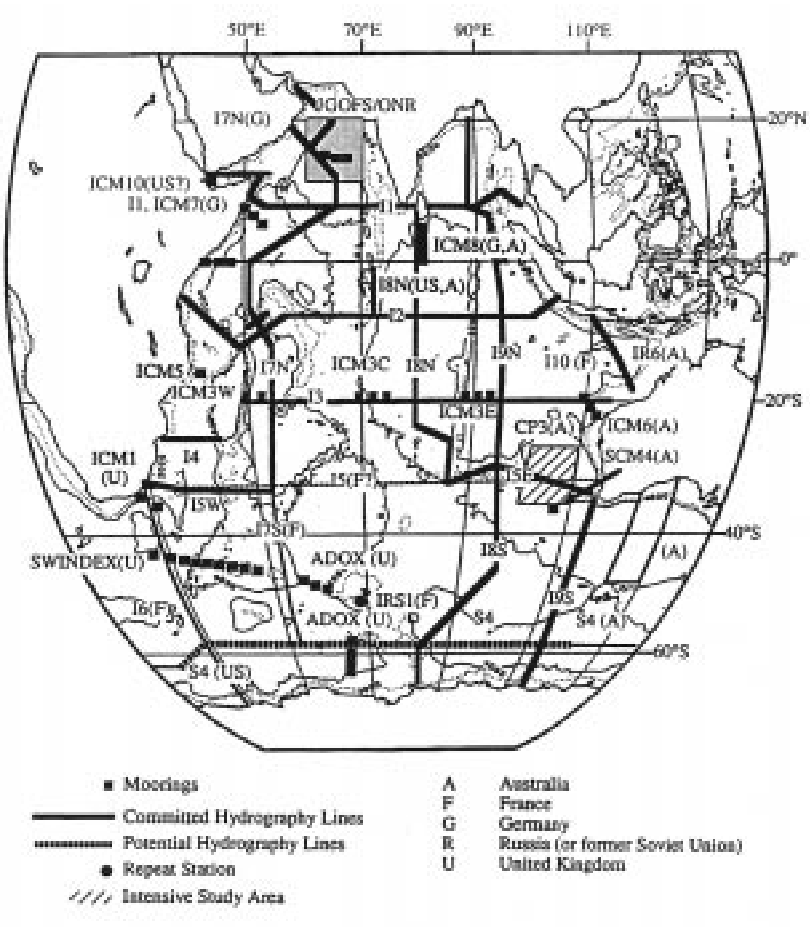

Figure 1. Locations of moorings and hydrography in and associated with the US contribution to WOCE Core Project 1 in the Indian Ocean.

WOCE Field Programme Activities in 1994

N. Penny Holliday, WOCE IPO

1994 is the mid-year of the WOCE Intensive Observation Period and the field programme is at a peak of activity. Numerous trans-ocean Pacific and Atlantic hydrographic sections are taking place this year, with floats and drifters being deployed on some. The Indian Ocean survey will mainly occur next year, but observations in that basin are beginning already. The deployment of XBTs continues but the network has suffered major cutbacks in 1994 particularly in the north and central Pacific. Current meter arrays deployed earlier in WOCE are being recovered and their records examined; meanwhile new arrays are being laid and existing ones re-set. ERS-1 and TOPEX/POSEIDON are sending back data with an accuracy exceeding expectations. The global sea-level network continues to expand.

The WHP One Time Survey is at a maximum of activity in the Atlantic and Pacific Oceans in 1994 with around 2200 hydrographic stations planned in these oceans, and a further 140 stations on two sections in the Indian Ocean (Table 1 and Figure 1).

Table 1. WHP One Time Survey Sections scheduled for 1994

Section	Country	Chief Scientist	Institution	Cruise Dates	Location
A2	Germany	Koltermann	BSH	October – November	48° N
A4*	Russia	Sokov	GOIN	?	32° N
A8	Germany	Müller	IfM Kiel	March 29 – May 11	11° S
A13	France	Arhan	IFREMER	End 94/Early 95	
A14	France	Arhan	IFREMER	End 94/Early 95	9° W – Africa 45° S
A15	USA	Smethie	LDEO	April 2 – May 21	
A17C	France	Mémery	LODYC	January 4 – February 13	N of 50° S
A17N	France	Mémery	LODYC	February 17 – March 21	
I8S	USA	McCartney	WHOI	December 1 – January 19/95	S of 32° S
I9S	USA	McCartney	WHOI	December 1 – January 19/95	Australia – Antarctica
P2	Japan	Okuda	JFA	January 7 – February 10	30° N
P2W	Japan	Fukasawa	Tokai University	January 15 – February 4	
P2W*	Japan	Ito	JODC	November – December	Japan – Hawaii
P9	Japan	Kaneko	JMA	July 17 – August 25	137° E, 142° E
P11S*	Australia	Church	CSIRO	June 24 – July 17	Papua New Guinea – 43° S
P15N	Canada	Garrett	IOS BC	September 6 – October 8	Aleutians – Hawaii
P15N	Canada	Freeland	IOS BC	October 13 – November 11	Hawaii – 15° S
P18N	USA	Johnson	PMEL	March 6 – April 6	Easter Is. – Baja
P18S	USA	Taft	PMEL	February 2 – March 3	Easter Is. – Antarctica
P18T*	USA	Butler	CMDL	January 7 – 29	
P21E	USA	McCartney	WHOI	March 27 – May 15	Peru – Tahiti
P21W	USA/UK	Bryden	JRC	May 19 – June 25	Papeete – Australia
P26	ROC	Liu	NTU	?	
P31	USA	Roemmich	SIO	January 25 – February 19	Samoan Passage

* indicates section is not to One Time standards

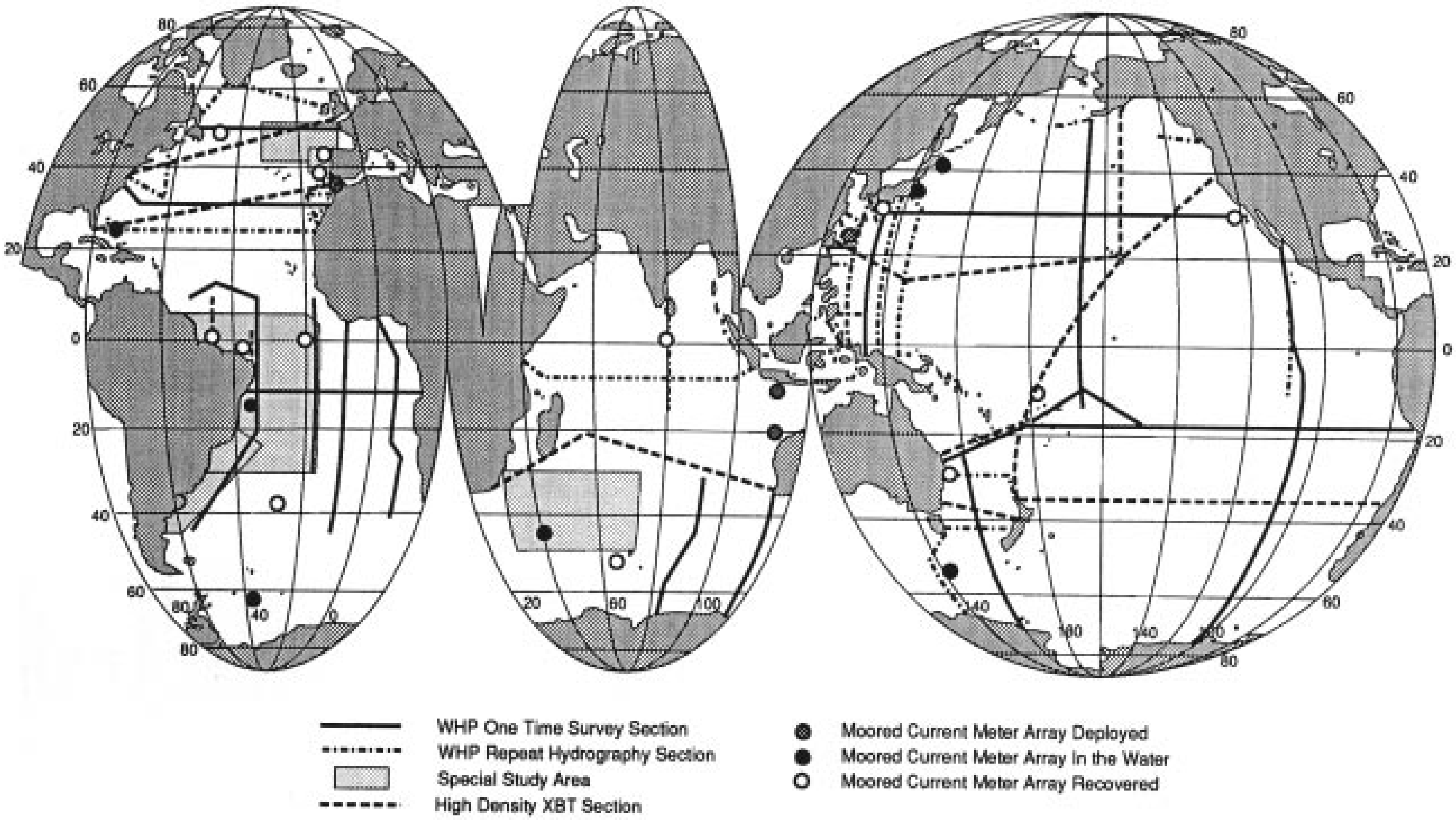

Figure 1. Major components of the WOCE Field Programme in 1994.

Table 2. WOCE Moored Current Meter Arrays recovered, in the water and deployed during 1994. (Arrays that do not fulfil complete WOCE requirements are in brackets).

Array	Country	PI	Institute	Laid	Redeployed	Recovered	Moorings	Current Meters
Recovered								
ACM6	Canada	Hendry	BIO	Aug 1993		1994/95	8	46
ACM7	Germany	Schott	IfM Kiel	Sep 1989	Oct 1990, Nov 1992	Mar 1994	3	24
ACM10	USA	Whitehead	WHOI	Sep 1992		Dec 1994	6	24
ACM11	France	Mercier	IFREMER	Nov 1992		Nov 1994	8	44
ACM13	Germany	Zenk	IfM Kiel	Dec 1992		Jun 1994	6	24
ACM27	Spain	Cabanas		May 1993		Mid 1994	2	10
ACM28	Portugal	Fiuza	Univ Lisboa	May 1993		Mid 1994	2	9
ICM8	Germany/Australia	Schott, Tomczak	IfM Kiel, Univ Sydney	Jan 1991	Feb 1992, Jul 1993	Sep 1994	6	28
(PCM2)	USA	Niiler	SIO	Aug 1992		Aug 1994	14	56
PCM3	Australia	Church, Meyers	CSIRO	Nov 1991	Sep 1992	1994	6	27
(PCM5)	USA	Hallock	NOARL	Jul 1992	Jul 1993	May 1994	4	13
PCM11	USA	Rudnick	Univ Washington	Sep 1992		Feb 1994	6	27
SCM6	UK	Dickson	MAFF	Feb 1993		Mar 1994	15	52
In the Water								
ACM1	USA	Lee	Univ Miami	Jun 1990	Feb 1992, Sep 1993	1995	4	21
ACM24	USA	Weatherly	FSU	Sep 1993		1995	16	64
PCM7	Japan	Imawaki	Kyushu Univ	Oct 1993	Oct 1994	Oct 1995	9	33
PCM6	USA	Owens, Warren	WHOI	Jun 1993		1995	9	28
(SCM2)	Germany	Fahrbach	AWI	May 1992	Dec 1992, Mar 1994	Mar 1995	3	14
SCM3	Australia/USA	Rintoul, Whitworth	CSIRO, TAMU	Oct 1991	Mar 1993	1995	4	20
SCM7	Germany	Fahrbach	AWI	Oct 1989	Dec 1990, Jan 1993	Mar 1995	7	27
SCM9	UK	Pollard	JRC	Apr 1993		Feb 1995	8	46
Deployed								
ACM9	Spain/USA	Ruiz, Candela		Feb 1994		?	?	?
(ICM4)	France	Fieux		Aug 1994		?	7	?
ICM6	Australia	Tomczak, Church	Univ Sydney, CSIRO	Sep 1994		Mar 1996	6	?
PCM1	USA/ROC			Oct 1994		1996	7	31

Table 3. High density XBT sampling in 1994

Line	Country	PI	Institute	Sections	Notes
AX3	Germany	Sy	BSH	8	8/year
AX7	USA	Molinari	AOML	2	Start delayed by VOS sinking. 4/yr after 94
IX15/21	USA	Talley	SIO	1	2 in 95, 4/yr after
IX28	France	Donguy	ORSTOM	3	
PX6	USA	Roemmich	SIO	4	
PX9	USA	Roemmich	SIO	4	
PX10	USA	Roemmich	SIO	2	
PX30/31	USA/Australia	Roemmich, Meyers	SIO, CSIRO	4	Brisbane to Fiji
PX34	Australia	Meyers	CSIRO	4	
PX37	USA/ROC	Roemmich	SIO	2	
PX38	USA/ROC	Roemmich	SIO	2	
PX44	USA/ROC	Roemmich	SIO	2	
PX50	USA	Talley	SIO	2	

During 1994 45 occupations of 26 repeat hydrography sections will take place, and 6 special study areas will be visited. Of these, 3 sections or areas will be occupied for the first time during WOCE, 1 will be occupied for a second year, 8 will be occupied for a third year, 8 will be occupied for a fourth year, and 11 will be occupied for a fifth year. More than 1700 repeat hydrography stations will be occupied during the course of the year. The sections and areas surveyed during 1994 are illustrated in Figure 1.

In the WOCE current meter array programme several previously deployed arrays will reach the end of their lives and be recovered, some will be redeployed and others are being laid for the first time. A summary of the moorings deployed, in the water or recovered during 1994 can be seen in Table 2 and in Figure 1.

Subsurface floats and surface drifters have been released from WHP cruises and from ships of opportunity since 1990. Over 2000 drifters and nearly 600 floats have been released up to the start of 1994, and a further 600 or so drifters and approximately 200 floats will be deployed this year. They will be distributed in the Atlantic, Pacific and Southern Oceans during 1994, with major deployments planned in the Indian Ocean for 1995.

The low density XBT sampling network has been expanding since before 1990 and by 1994 around two-thirds of the low density lines have some commitment to them. Many sections recently identified as high priority due to their lack of previous coverage will have sampling starting in 1994. These include lines in the Atlantic, Indian, southeast Pacific and Southern Oceans. However, these improvements are tempered with the reduction of sampling particularly in the central tropical and north Pacific where some of the longest XBT time series will cease in 1994 due to a shortfall in funding. In addition to the low density sampling, there are several eddy-resolving high density sections which are required to be repeated seasonally. Out of the required 28 high density sections, 5 will be sampled at least 4 times in 1994, and 8 sampled between 1 and 3 times during the year (Table 3 and Figure 1). The remainder are uncommitted and sampled at low density.

Data are currently being collected at around 100 sea level stations which are in the WOCE network. Many of those (mainly in the Pacific and Indian Oceans) are sending data in real time to the Data Assembly Centre (DAC) at the University of Hawaii. These data and some products are available online within a short period of collection. All sites will eventually send their data to the delayed mode Sea Level DAC in Bidston, UK.

With the high level of activity in the field programme this year, comes an associated increase in activity in the data management system. All the WOCE DACs are receiving data, and a variety of products are being generated and distributed. Delays in the data flow system still exist but are being addressed by the WOCE Data Products Committee (formerly the Data Management Committee), as well as the individual programme planning committees.

The Spreading of Antarctic Bottom Water into the Indian Ocean – First Results of the UK ADOX Programme

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The Antarctic Deep Outflow Experiment (ADOX) of the UK WOCE programme is designed to describe the rates and pathways by which Antarctic Bottom Water (AABW) spreads from the Weddell–Enderby Abyssal Plain into the Indian Ocean. It is based on a combination of direct current measurements in the two main topographic gaps used by this abyssal throughflow at either end of the Kerguelen Plateau, and extensive tracer work to track the outflow plume and to partition it into its source watermasses. The deployment phase of ADOX took place from 6 February to 18 March 1993 aboard RRS Discovery Cruise 200, and the recovery phase was only recently completed with the working of an 8220 mile cruise track from Cape Town to Mauritius between 19 February and 31 March 1994 (RRS Discovery Cruise 207). As international WOCE plans for the Indian Ocean take shape (*e.g.* US WOCE Notes, 6(1) pp. 5, 9 and p.18 of this issue), this article presents the first ADOX results on the deep exchanges that take place through its southwestern boundary, and sets them into the context of earlier work by others. The results presented here will largely concern the tracer programme since although 16 out of 18 current meter moorings were recovered, the analysis of these data is at too early a stage to provide transport estimates.

As Warren (1981) reminds us, we have realised for more than a century that the deep Indian Ocean is filled with water from the Antarctic (Carpenter, 1868), and more than a third of a century has elapsed since Stommel and Arons (1960) first provided us with a realistic dynamical framework for the abyssal circulation. Yet, even models as finely-resolving as FRAM have highly-smoothed topography and no real bottom water formation process, so that they still need observational detail to confirm the pathways and spreading-rates of the deepest layers through the complex topography of the Southern Ocean. Fortunately we have a whole range of old and new tracers capable of tracking as delicate

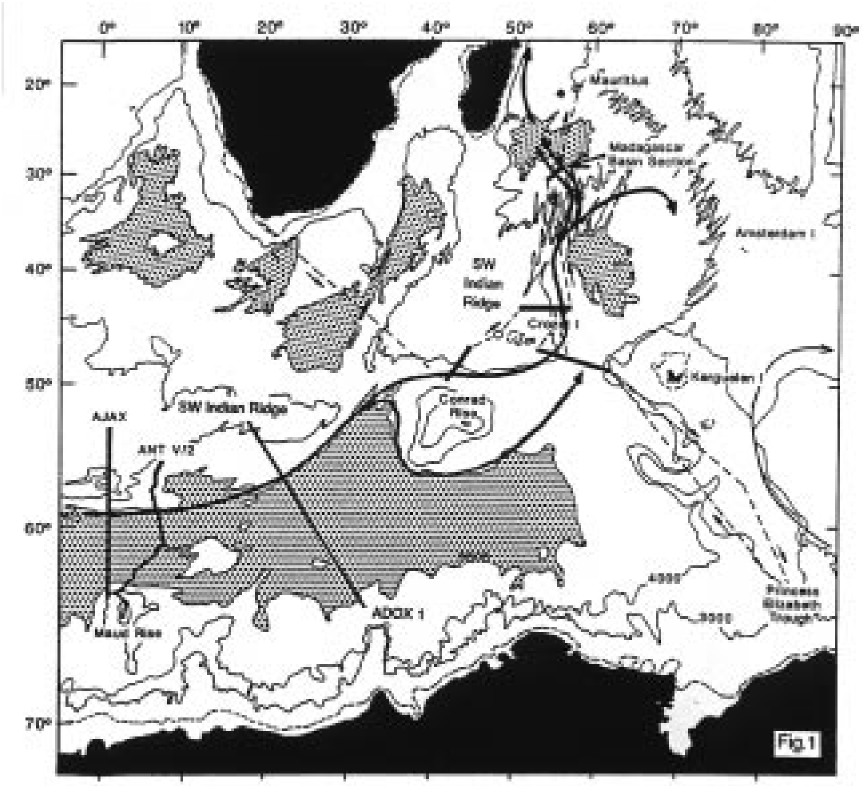

Figure 1. Topographic chart showing section locations and ADOX-2 cruise track. Heavy black curve denotes the author's interpretation of tracer data for pathway of Antarctic Bottom Water.

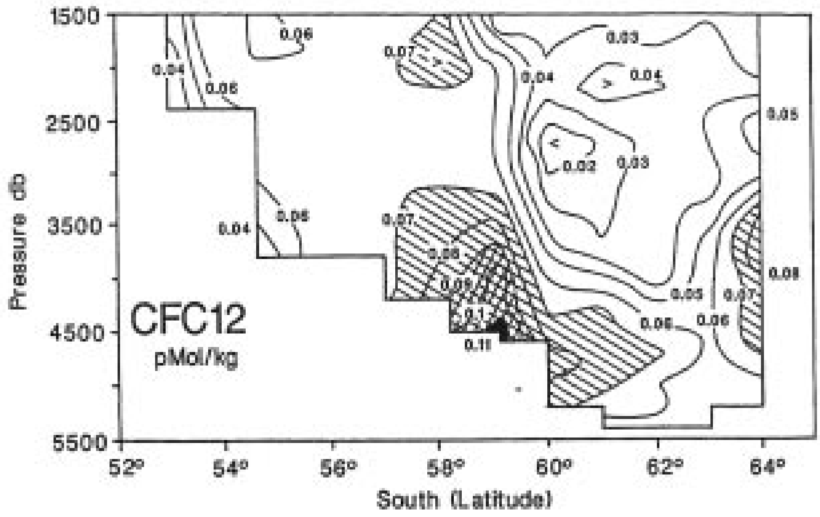

Figure 2. CFC-12 distribution on AJAX leg 2 (Weiss et al., 1990).

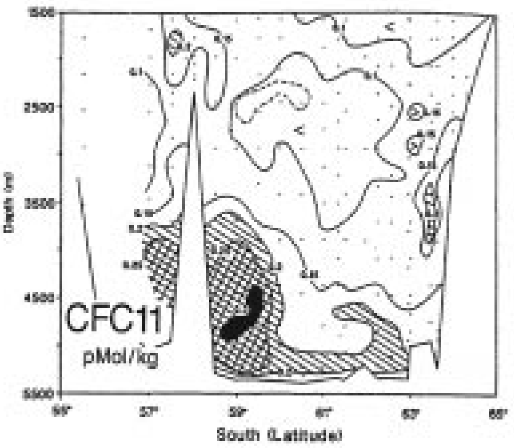

Figure 3. CFC-11 distribution on ANT V/2 (east). Data kindly supplied by Dr R.F. Weiss, SIO.

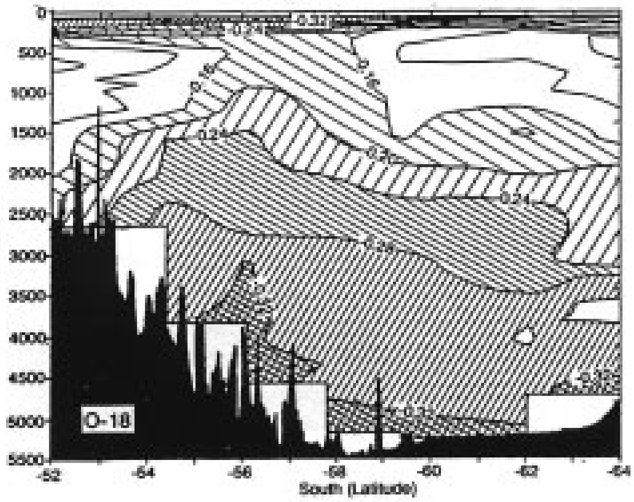

Figure 4. O-18 distribution from SW Indian Ridge to Gunnerus Ridge of Antarctica (per mil vs. SMOW). ADOX-1 analyses by Dr R. Frew (U. Otago and UEA).

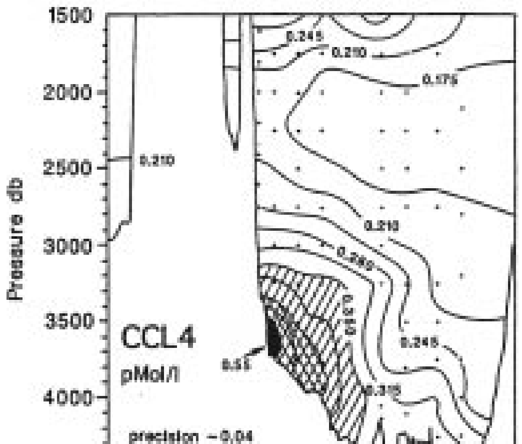

Figure 5. CFC-10 distribution in the Crozet–Kerguelen Gap during ADOX-1 (preliminary data by Watson, Haine, Liddicoat and Krysell).

a feature as the Antarctic outflow plume over thousands of kilometres.

As the newly-formed AABW plume emerges from the western Weddell Sea, its initial spreading is beautifully described by Carmack (1977, his Figures 10–13) as a cold, slightly fresh, dense, oxygen-rich, near-bottom tongue, with one branch leaking north around the Scotia Arc to enter the S. Atlantic, but with the main plume continuing east against the foot of the SW Indian Ridge. At the Greenwich Meridian, (location Figure l; section Figure 2) we can use one of the earliest of the high-quality CFC lines – the north-south AJAX Leg 2 line of January–February 1984 (Weiss *et al.*, 1990) – to show the plume continuing east as a compact CFC-12 maximum at 3500–4500 m depth, still hugging the base of the SW Indian Ridge. From this point eastwards, the CFC signal is perhaps our best descriptor of the AABW core if the precision is as high as in these measurements (around 0.005 pmol/kg). Dr Ray Weiss, SIO, has kindly supplied the CFC-ll and -12 data from the Polarstern ANT V/2 (east) transect of August–September 1986 to confirm the continued integrity of the core in the same location relative to the Ridge at 6°E, shown in this case in the CFC-11 distribution (Figure 3).

The first SE-bound leg of the ADOX-1 cruise in February 1993 consisted of only 7 widely-spaced stations, but this was adequate to identify the location of the plume in a variety of tracers, even though we cannot assume to have entered the core on this occasion. By way of contrast, Figure 4 describes it in the O-18 isotope distribution from the ADOX-l analyses by Dr Russell Frew of Otago University and UEA, Norwich. Since ice is isotopically lighter than seawater this is a useful tracer of past involvement in sea ice formation and melting, and although ice-melt causes large changes in salinity, it leaves the delta O-18 almost unchanged. Of greatest relevance to ADOX is the fact that while the core of the outflow at 56°S (Figure 4) has the isotopic composition of Weddell Sea Bottom Water (Schlosser *et al.*, 1990), the bottom water encountered in the Princess Elizabeth Trough between Kerguelen Plateau and Antarctica (Figure l) was found to have been formed by distinctly different processes, including little or no glacial meltwater as found in AABW from the Weddell Sea. (Russell Frew, pers. comm.)

The further spreading of AABW through the Crozet–Kerguelen Gap and into the Indian Ocean has been described from a range of direct and indirect indicators. For example, Mantyla and Reid (1983) use potential temperature and salinity (both minima), oxygen and silica (both maxima) to describe the deep inflow and its subsequent alteration by mixing with overlying water as it flows north. The new availability of high quality CFC data extends this description. First, although we can readily employ three end-member mixing models between North Atlantic Deep Water, Upper Circumpolar Deep Water and AABW to calculate the percentage distribution of AABW in the Crozet–Kerguelen Gap, the CFCs (*e.g.* CCL4 in Figure 5; from ADOX-1 analyses by Andrew Watson, PML[1], Tom Haine, PML/UEA, Malcolm Liddicoat, PML and Mikael Krysell, U. Goteborg, Sweden) remind us that the AABW plume arrives in very much more discrete form than the long-term steady state distribution. In fact the core lying against the foot of the slope on the Crozet side of the Gap in Figure 5 appears little different from the compact feature that the AJAX scientists found on the Greenwich Meridian. The fact that the core passing Crozet does not extend much below 4200 m is explained by the topography immediately upstream, where the passage between Conrad Rise and the Crozet Plateau has a sill about this depth, forcing any deeper part of the plume to divert south of the Conrad Rise and to enter the Crozet–Kerguelen Gap further east and deeper (as it appears to do in Figure 5).

From this point northwards, the ADOX-2 team (Haine, PML/UEA and Liddicoat, PML, for CFCs and Don Kirkwood and Ali Reeve of MAFF[2] for conventional chemistry) traced the plume north along the west wall of the Crozet Basin as a dense ($\sigma\theta > 27.83$), cold, O_2-rich, silica-rich, near-bottom, CFC-maximum layer to the point where it passes through the SW Indian Ridge and enters the Madagascar Basin. The literature (e.*g*. Warren, 1978) is helpful in narrowing down the bulk of the throughflow to two Fracture Zones – the Atlantis II F.Z. at 57°E, and the Melville F.Z. at 60.5°E – but is less certain about the effective sill depth, or the onward route across the Madagascar Basin. Based on the location of coldest and freshest water and on geostrophic transport estimates, Swallow and Pollard (1988) tentatively suggest that “the deep water appears to make its way more or less directly across the Madagascar Basin,” rather than using the long route around its western edge, and in Figure 6 their conclusion is amply justified in the northernmost of the ADOX-2 CFC sections. CFC-12 has largely disappeared by this point but the preliminary CCL4 (carbon tetrachloride) data show clear evidence of two off-bottom cores at 3900–4700 m in the middle of the pathway sketched by Swallow and Pollard (their Figure 1). Finally, more than 10,000 km from where the AABW plume first turned east from the Peninsula, Warren (1974, his Figures 7–9) shows from the deep oxygen, temperature and salinity distributions that it has formed up once again into a single core, on the bottom, pressed against the foot of the Madagascar slope, as it continues north towards the Amirante Trench.

Though we have concentrated here on the simplest use of ADOX tracers (to describe the path of the outflow), their key role will come when the spatial changes observed in core concentrations, including any “extinctions”, are used to estimate spreading rates for the AABW plume. Their special importance lies in the fact that these estimates should reflect the *broadscale* spreading of AABW in the

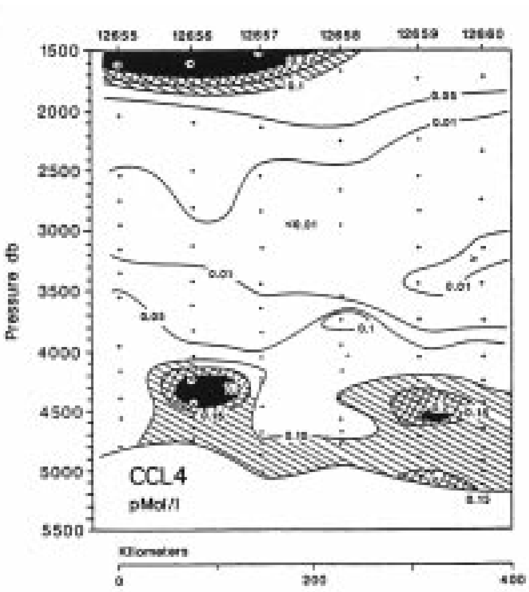

Figure 6. CFC-10 distribution in the Madagascar Basin section of ADOX-2 (preliminary data by Haine and Liddicoat).

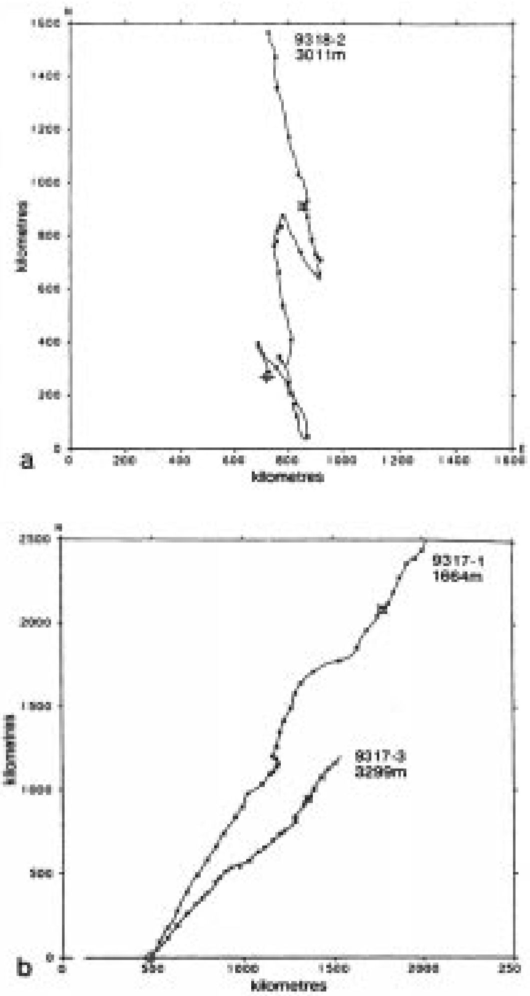

Figure 7. Progressive vector diagrams for deep, one-year current meter records (a) west and (b) east of Crozet (ADOX-2 data). Ticks are at 10 day intervals.

(1) Plymouth Marine Laboratory.
(2) Ministry of Agriculture, Fisheries and Food.

abyssal Southern Ocean, and will therefore complement and perhaps differ from the direct measurements of current speeds where the deep throughflow is constrained by topography, as in the Crozet–Kerguelen Gap. These direct and indirect measures of flow together with a variety of events in the current meter records will be reported in a future issue of this Newsletter. Meanwhile, the year-long progressive vector diagrams of Figure 7 provide three preliminary illustrations of the throughflow at its most direct, either side of Crozet Island; 7a is from a near-bottom record at 3011 m depth in the deep cleft west of Crozet, while 7b shows records at 1664 m and 3299 m depth, respectively, an a mooring laid east of Crozet, against the west "wall" of the Crozet–Kerguelen Gap.

The excellence of the PML-led tracer team, the speed and analytical precision of the instrument that they evolved (GCEC, with liquid nitrogen trap and 10-minute throughput of samples), and the support of the UK WOCE programme were all essential to the success of ADOX and are all gratefully acknowledged.

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Monitoring Pressure Difference Across the ACC

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In the austral summer of 1991–92, we began a programme supported by the National Science Foundation to measure the pressure difference across the Antarctic Circumpolar Current at a nominal depth of 1000 m. The purpose is to monitor transport fluctuations of the ACC at the three choke points, and to study the phase relationship of changes in transport. The US component of this project covers the choke points south of Africa and Australia; the British group, led by Ian Vassie of Proudman Oceanographic Laboratory, instrumented Drake Passage.

The US project was designed as a ship-of-opportunity programme with logistic support arranged through scientists in South Africa and Australia. A self-recording, free-fall instrument package was developed to reduce the technical requirements for deployment. The package consists of a Sea-Bird Seacat recorder with a Paroscientific Digiquartz pressure sensor mounted in an aluminum frame with four 17-inch glass spheres; the frame is connected to a steel anchor ring via an EG&G BACS acoustic release. Pressure, temperature and conductivity are sampled hourly. For redundancy, two pressure recorders were planned at each site, one to be recovered and replaced after two years, and one to remain in place for the duration of the four-year project.

Four sites south of Africa were instrumented: Cape Town (34.5°S, 18°E), Shannon Seamount (43°S, 2°E), Bouvet Island (54°S, 3°E) and SANAE base (70°S, 3°W). The deployments were made between March and June 1992 on three different cruise segments by RV Polarstern with coordination assistance from Geoff Brundrit and Howard Waldron of the University of Cape Town. One of the Cape Town packages was recovered and replaced in November 1993 by RV Ewing; Vere Shannon of South Africa's Sea Fisheries Research Institute facilitated the servicing of the other sites south of Africa from the S.A. Agulhas, and the RV Africana between December 1993 and March 1994.

Two sites south of Australia were instrumented with the assistance of Steve Rintoul, CSIRO/Oceanography, Hobart: two packages south of Hobart were deployed from RV Aurora Australis in October, 1991; a second pair was deployed near the French base Dumont D'Urville by the supply ship Icebird in January 1992, after ice cover prevented the Aurora from reaching the site earlier. A Hobart gauge was recovered in January 1994 from the Aurora, but neither package on the southern side surfaced after being released. New gauges were installed at both sites. Steve Rintoul and John Church, with the cooperation of the Australian

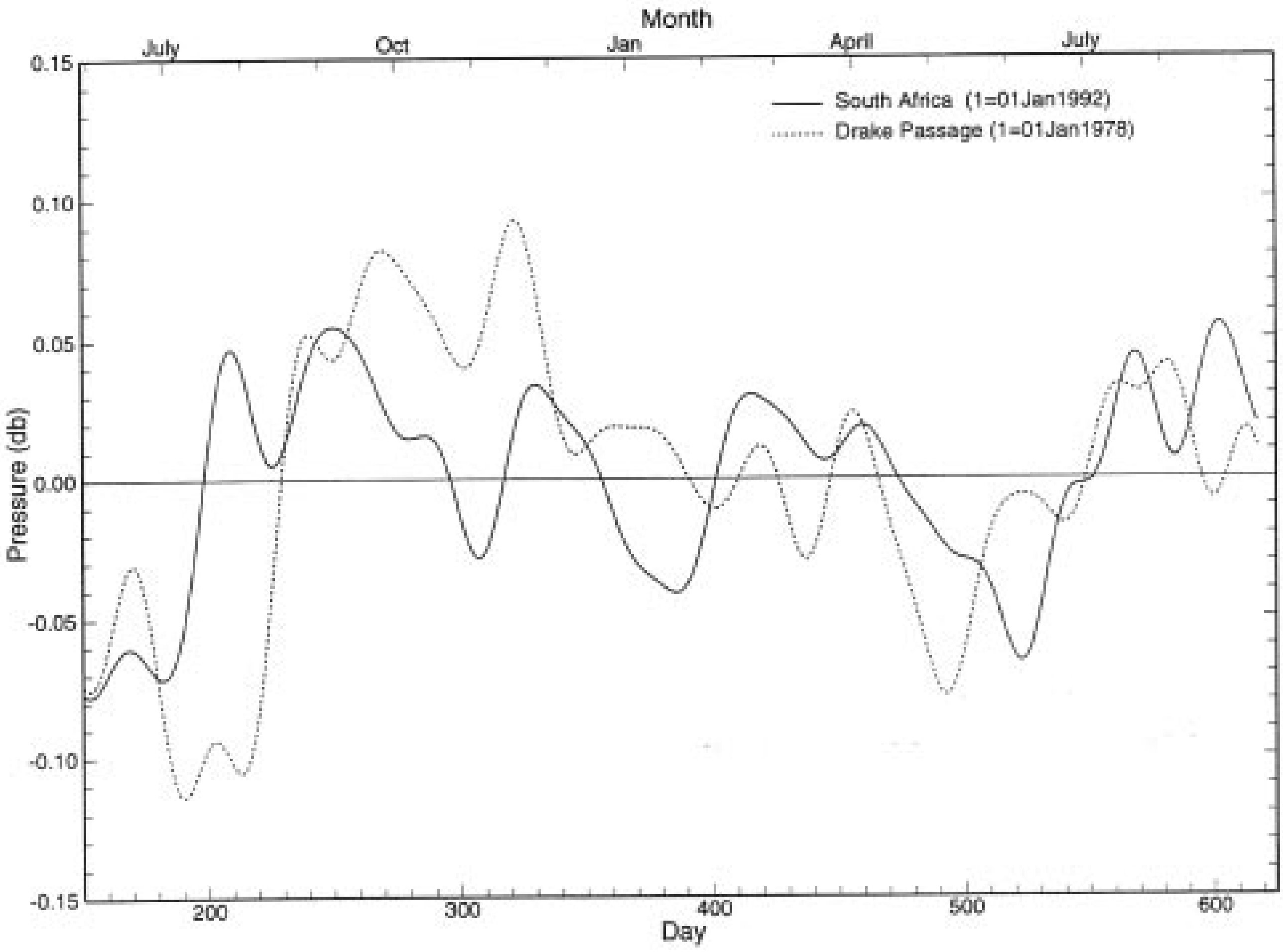

Figure 1. The solid line shows the north-south pressure difference (in decibars) between Cape Town and the Antarctic Continent over a period of about 15 months between June 1992 and September 1993. The dashed line shows the pressure difference across Drake Passage fourteen years earlier, i.e. for the corresponding months in 1978/79. The means have been removed from both series, and they have been low-pass filtered (30-day) for clarity.

Antarctic Division, arranged for an extension of the Aurora Australis cruise, and the transshipment of trawling gear and a trawling specialist to the French base to attempt a recovery. Unfortunately, the low-profile (1-m) packages could not be dragged up. The packages have battery life-times of five years, and we hope to mount another attempt to recover them.

The five instruments recovered have produced nearly flawless records. The figure shows the 30-day low-passed pressure difference between Africa (Cape Town) and Antarctica (SANAE). For comparison, the figure also shows the pressure difference across Drake Passage during the International Southern Ocean Studies programme. Although the two time-series are separated by fourteen years and the breadth of the South Atlantic, they show striking similarities including a rapid increase in pressure difference during the first austral winter; at Drake Passage, this signals a sudden increase in the transport of the ACC (Whitworth and Peterson, 1985), but a similar correlation south of Africa remains to be demonstrated.

Perhaps the most rewarding aspect of this programme has been the superb international cooperation we have received when logistical difficulties seemed to threaten the entire project: we originally proposed to make the deployments and recoveries on four cruises of two ships; in the end, it took ten cruises and six ships. In addition to those already mentioned, we are indebted to the following for assistance: Heinz Miller, Henry Valentine, Johann Lutjeharms, Michael Spindler, Peter Lemke, Silvia Garzoli, Jay Simpkins, Dennis Root, Peter Claassen, Chris Rohleder, Denzil Miller, Brian Super, D.D. van Rooy, Pud Taylor, and Jo Jacka.

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BPR Measurements of the ACC Across the Drake Passage

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At the present time POL is involved in "Climate Change" programmes such as WOCE through its ACCLAIM (Antarctic Circumpolar Current Levels by Altimetry and Island Measurements) project (Spencer *et al*., 1993). This requires the operation of Bottom Pressure Recorders (BPRs) in the Southern Ocean for periods of 5 to 10 years to measure pressure gradients across the ACC. An important aspect of the work is to derive variations in the transport of the current through the Drake Passage and at the other choke points, south of Africa and south of Australia. To monitor these critical exchanges between the world's oceans, collaboration between the US and the UK was organised to instrument the three choke points over a five year period. A large degree of international collaboration was required as access to these remote areas is always logistically difficult. From the UK point of view the assistance of the British Antarctic Survey (BAS) was essential in providing technical and logistic support on their supply and scientific cruises to the Antarctic bases.

The measurements in the Drake Passage formally began in November 1991 when two BPRs and a pair of Inverted Echo Sounders were deployed in the far western section of the passage (POL 4 and POL 5 in Figure 1). It became apparent however that reaching these positions annually would place an unreasonable demand on ship time. It was unlikely therefore that the instruments could be sustained for a substantial period. In November 1992 the instruments were recovered on the RRS Bransfield and were re-sited along a line between Elephant Island and Burdwood Bank (POL 6 and POL 8 in Figure 1). Before this time, from 1988 until November 1991, BPRs had been recording pressure at locations POL 1, POL 2, and POL 3 (Figure 1). By international agreement through the WOCE Core 2 working group this section became the recognised choke point and WOCE hydrographic section SR1. The transect was arranged to lie under an orbital track of ERS-1 to complement the data with satellite altimetry. The positions of the two recorders were 54°56'.5S, 58°23'.6W (POL 8) and 60°51'.0S, 54°42'.9W (POL 6) in 1000 m water depth.

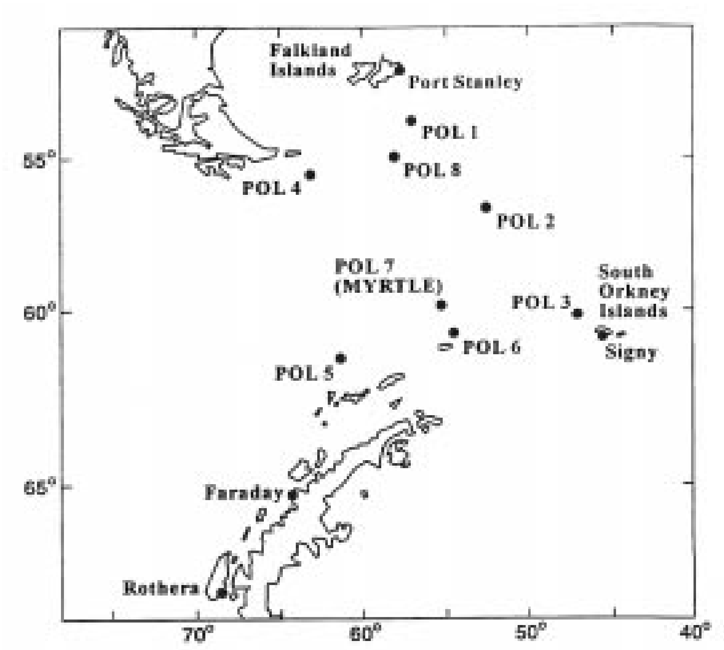

Figure 1. Positions of POL BPR moorings since 1988 to the present day. Positions 6, 7 and 8 lie along the Drake Passage choke point between Elephant Island and Burdwood Bank. Also included are the positions of the coastal stations where sea level recorders have been installed.

Two of our fieldwork group again joined the RRS James Clark Ross in December 1993, during a BAS cruise, for recovery and redeployment of the instruments. This provided us with the first year of measurements from the section. Results are shown in Figure 2. At the same time a team from the James Rennell Centre performed full depth CTDs and measured the upper ocean currents with ship-borne ADCP (International WOCE Newsletter No. 15, page 13). These furnished the best estimate so far of the volume transport. The long term BPR data provides a measure of the representativeness of a particular observational period and gives values of inter-annual variability.

Near the southern position of the section, our Multi Year Return Tidal Level Equipment (MYRTLE) was deployed (near POL 6). The instrument is capable of making continuous measurements of sea pressure and temperature over a 5 year period using high precision sensors. Onboard data are transferred by optical link to solid state memory contained in several buoyant, releasable data capsules which provide the means for data retrieval at the surface. The first one year of data was successfully brought back in December 1993. MYRTLE was placed at 59°43'.7S, 55°29'.5W (POL 7) at a depth of 3690 metres where the instrument continues to operate. A feature of figure 2 is the larger amplitude of the MYRTLE data compared with Drake South. No adequate explanation of this has yet been found but instrumental causes have been eliminated.

The ACCLAIM programme of measurements also comprises a network of island stations. Some of these are concentrated around the Drake Passage. They include Port Stanley, Signy Island, Faraday Base and a recent installation at Rothera. Faraday has a valuable 26 year record of sea level from the period when it was operated by BAS. Rothera may in the future become a replacement for Faraday as the operational logistics are easier. At two of these stations the instruments are the result of development work on a means of fixing the datum level of the measurements to a high accuracy in order to guarantee stability on long time scales. Following initial tests in the UK, an operational version of the new instrument was produced and deployed at Port Stanley and Rothera. Initial results suggest that absolute accuracies of a few millimetres can be obtained. Data from the BPRs have been correlated with signals in the Inverted Echo Sounders and have been studied in conjunction with FRAM (the Fine Resolution Antarctic Model). With the University of East Anglia, work is proceeding on a comparison of the Drake Passage data with AVHRR images to test the assumption that cross-channel differences are truly representative of transport and to study the effects of frontal movements and seasonal warming of the surface layers.

Already completed is an analysis of ACC flows between Amsterdam and Kerguelen in the Indian Ocean which demonstrated the symbiosis required between the study of *in-situ* data, altimetry and numerical modelling (Vassie *et al*., 1994). Similar work with the Drake Passage data is underway. Much of the data has been analysed for tides which are important to the increasing number of ocean tide models that are now being developed. Global and regional tidal models of higher resolution are becoming increasingly important for the correction of the present generation of altimeters.

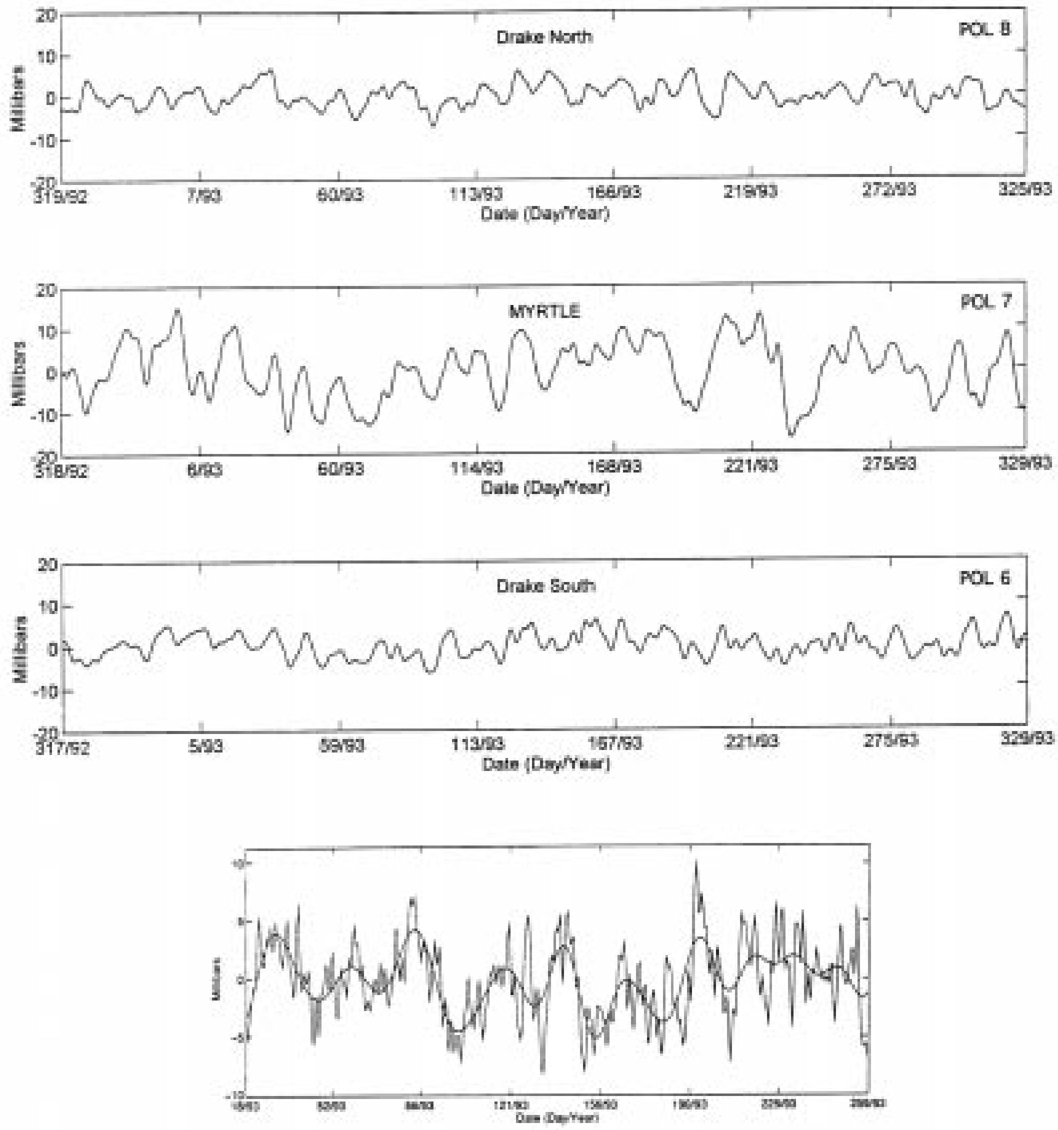

Figure 2. First results from the Drake Passage Choke Point. The figure shows one year of de-meaned, low-pass filtered bottom pressure data from the three positions POL 8, 7 and 6. The bottom panel shows POL 8 minus POL 6. Amplitudes are similar to those reported by Whitworth and Pillsbury (pp.28—29).

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Ocean Heat Transport – A Precursor to the Cold Winter of 1992 in the South-West Pacific Ocean

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Introduction

We present a study of a substantial climate anomaly in the southwest Pacific Ocean. The austral winters of 1992 and 1993 were the coldest and third coldest on record in New Zealand. There were periods of heavy rainfall and snow in areas where it is rarely seen. According to press reports, one particularly severe snow-storm resulted in the loss of over a million livestock. The ocean surface layer was also unusually cold in the waters surrounding New Zealand. Sea surface temperature (SST) was 1 to 2°C below seasonal average and cooling extending to about 200 m depth.

Data

As part of the WOCE Voluntary Observing Ship Programme oceanic variability in the south-west Pacific Ocean has been observed using three high-resolution XBT survey lines. The shipping routes (Fiji–Brisbane; Auckland–Fiji; Sydney–Wellington) together with the Australian coast, enclose the "Tasman Box" region (Figure 1). Monitoring of the Tasman Box is a collaborative Australian/US effort, involving CSIRO Division of Oceanography (Rick Bailey and Gary Meyers), and Scripps Institution of Oceanography (SIO). Temperature data are collected on these lines using an automatic XBT launcher developed at SIO. Station spacing is eddy-resolving, with XBT profiles approximately 40 km apart midtrack and 10–20 km apart near the end-points and topographic features. Lines are run on at least a quarterly basis. Sampling along the Brisbane–Fiji and Sydney–Wellington transects commenced in early 1991 (10 and 11 cruises respectively), and along the Auckland–Fiji track early in 1986 (30 cruises). During September 1992, WHP leg P14C followed exactly the Auckland–Fiji XBT survey track. Measurements included fifty-two full depth CTD stations. Thus with eight years of temperature observations available along the Auckland–Suva route, and nine realisations of the whole Tasman Box, we can now reasonably assess interannual variability in the south-west Pacific region.

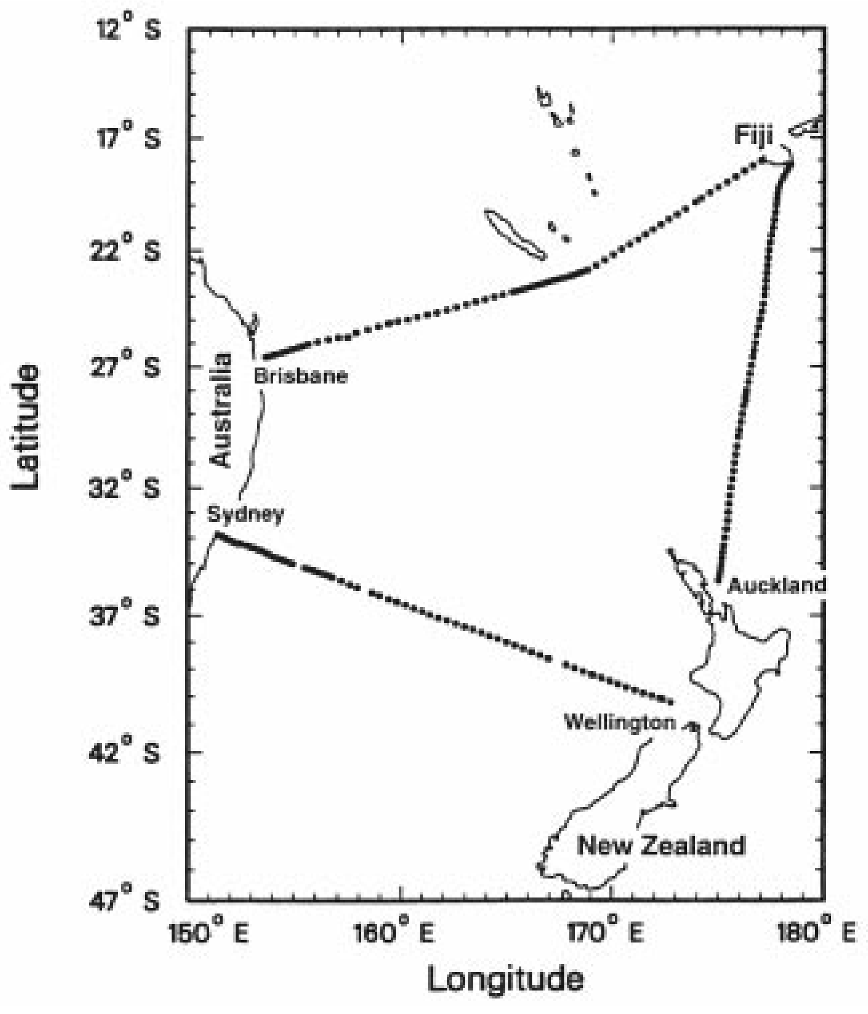

Figure 1. The three high-resolution XBT shipping routes (Brisbane–Fiji; Wellington–Sydney; Auckland–Fiji) that form the Tasman Box in the South Pacific Ocean.

The Cold Oceanic Surface Anomaly of September 1992

During the late winter of 1992 extraordinarily cold and wet weather prevailed in the south-west Pacific region. The South Pacific Climate Monitor reported persistent, cool continental temperatures in the area, with heavy rainfall and unusual snow. A blended composite of monthly air temperature data from seven New Zealand stations (Figure 2) show September 1992 to be 1.5°C cooler than the 1951–80 average. Indeed, most of 1992 was anomalously cold, being 1°C cooler in the annual average. Winds at a number of coastal sites on New

Zealand's North Island shifted from mild northerlies to cooler south-westerly conditions (Thompson and Basher, 1993).

The surface layer in the south-west Pacific was also anomalously cold. The WHP section P14C in September 1992 found cold surface temperatures and deep mixed layers near New Zealand (Figure 3a). Figure 3b shows the temperature anomaly for the top 200 m of P14C, computed as a departure from the annual cycle from eight years of XBT temperature measurements along the transect. SSTs of 15°C near New Zealand are up to 1.5°C cooler than those generally found at this time of year. The cooling extends from the New Zealand coastline to about 24°S, northward of which warmer than average temperatures occured in the top 200 m.

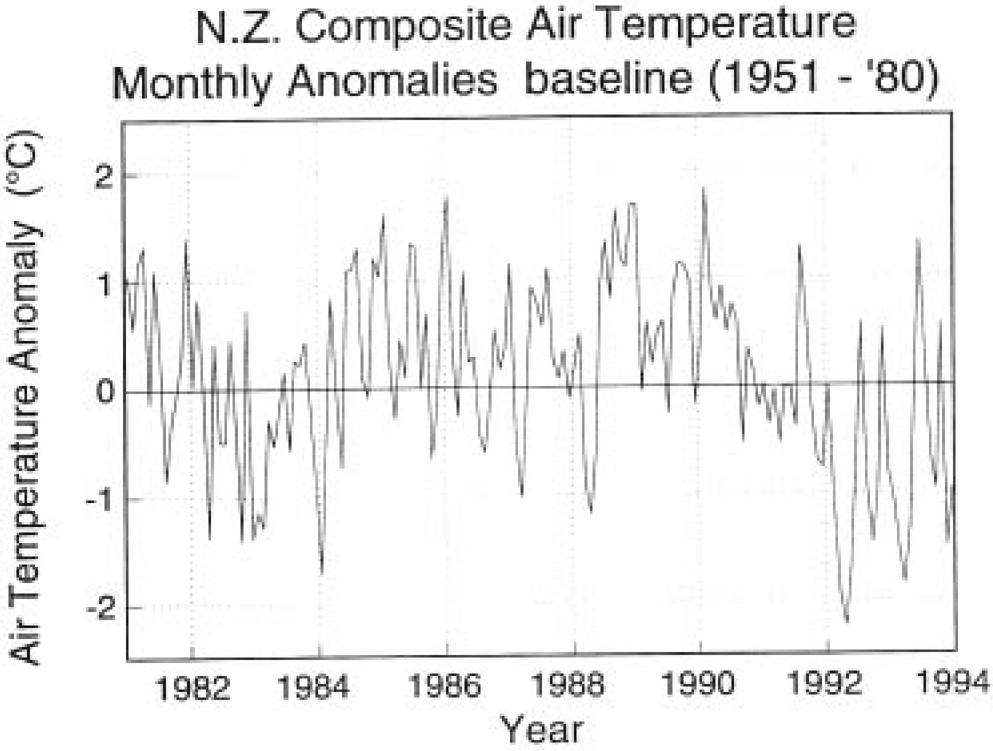

Figure 2. Monthly anomalies of air temperature from a composite of seven stations throughout New Zealand, 1980–93. The anomalies are computed as a departure from the 1951–80 mean. This data was kindly provided by Jim Salinger, National Institute of Water and Atmospheric Research, New Zealand.

In Figure 4 the quarterly time series of SST and the vertically averaged temperature for the top 200 m are shown, spatially averaged over the 30°S to 35.5°S latitude bands, along the Auckland–Fiji track. The September 1992 SST and upper layer temperatures are the coldest of the record. Less than 0.5°C separates the average sea surface from upper layer temperatures at this time. This is indicative of the 220 m deep isothermal layers shown in Figure 3a in the seas north of Auckland. The anomalously cold region is known to be the formation site of the Subtropical Mode Water (STMW) in the south-western Pacific. Roemmich and Cornuelle (1992) attributed the enhanced presence of STMW in spring of 1986 to intensified subduction and active formation of the mode water during winter of 1986, as evident by the cooler SST and deep mixed layers present at that time. The warmer, shallower mixed layers of 1987 to 1991 seen in Figure 4 resulted in a lower STMW inventory (Roemmich and Cornuelle, 1992).

Comparably, the Sydney–Wellington transect of September 1992 also showed a cold mixed layer, isothermal to a depth of 250 m, off the west coast of New Zealand. Along this transect the SSTs were 0.5°–1.0°C cooler than normal at this time of year.

What Caused the Cold Anomaly?

In the following we will present a likely scenario of the relative roles of oceanic and atmospheric forcing in producing the unusual climatic conditions.

Geostrophic transport relative to 800 m, for waters above the 12°C isotherm was estimated from nine realisations of the Tasman Box during 1991–93 (Figure 5). In this calculation the NODC hydrographic data set of CTD observations provided a mean T–S and hence density estimate at grid points along the tracks. We have combined the contributions from the Brisbane–Fiji and Sydney–Wellington transects as they represent mass flow into the box, primarily via the warm East Australian Current (EAC), and the cooler Tasman Current respectively. Across the Auckland–Fiji line there is mostly eastward surface flow out of the Tasman Box, with water tending to recirculate in the South Pacific subtropical gyre (Reid, 1986). The total transport for all three transects is given in Figure 5 by the solid line.

The most striking feature in Figure 5 is the horizontal divergence of 13.5 Sv in the surface waters warmer than 12°C early in 1992. This appears to be largely due to a decrease in the volume flow of the EAC across the Fiji–Brisbane transect. In December 1991, the total transport of

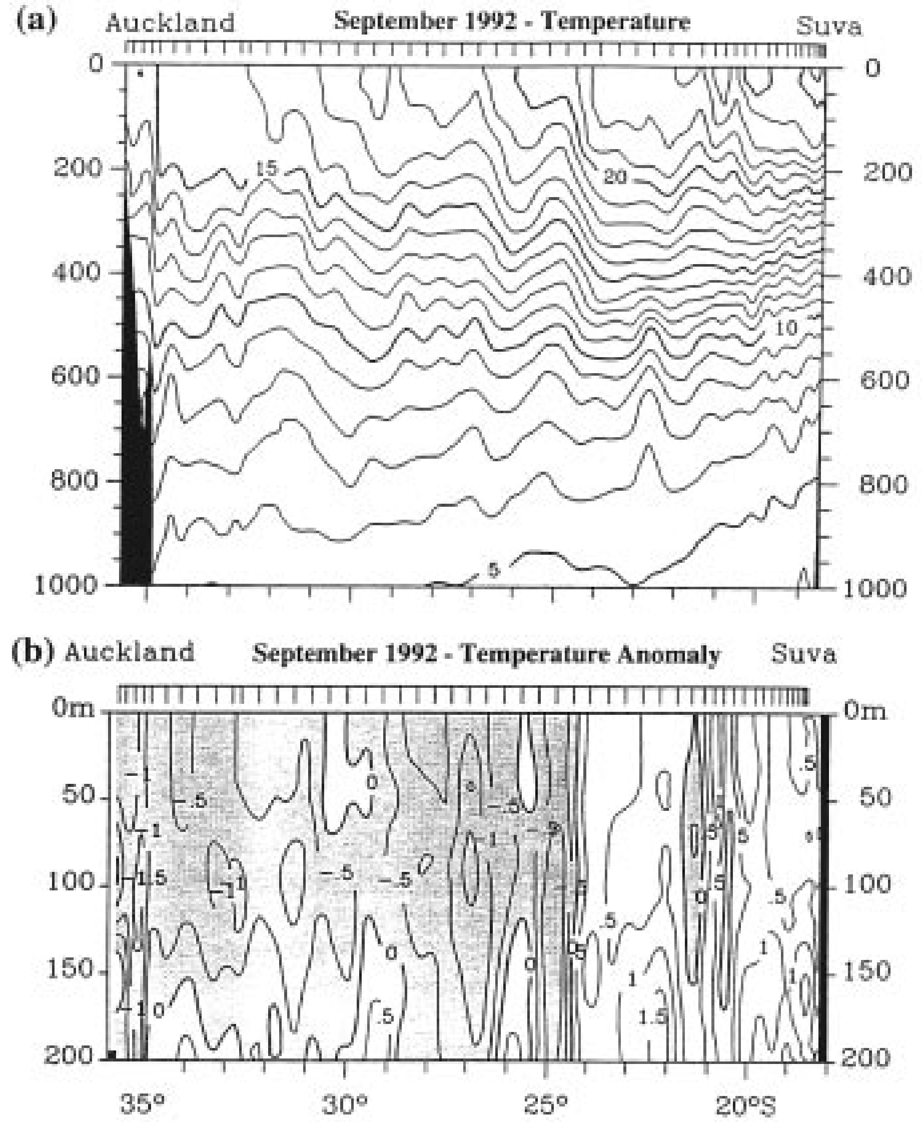

Figure 3. (a) Temperature and (b) anomalous temperature (with the annual cycle removed) profiles from P14C between Auckland and Suva, September 1992. Negative anomalies are shaded.

water warmer than 12°C across this transect was 14.6 Sv southward. This diminished to 3.5 Sv southward in March 1992. Subsequently, there was also a decrease in the flow across the Sydney–Wellington line where the southward flow in the EAC terminates. At the same time, there was a substantial increase in the outflow of the Tasman Box eastward across the Auckland–Fiji transect. The transport of 17 Sv was the largest in the eight years of measurements on this transect.

In the mean, the geostrophic divergence of the Tasman Box should be balanced by wind-driven Ekman convergence of the upper layer. Ekman transport estimates, using the 1991–92 ECMWF wind stress field, show a maximum of 4.4 Sv in the Ekman convergence time series did occur early in 1992, coinciding with, but obviously not balancing the geostrophic divergence of 13.5 Sv out of the Tasman Box. It is suggested that the thinning of the warm surface layer during early 1992 was balanced by an upward flow of deeper cooler water. Indeed, high nutrient and low dissolved oxygen concentrations in the surface layer on P14C indicated recent entrainment of thermocline waters. The anomalous transport of heat by ocean currents out of the box, if replaced by colder deeper water, may have preconditioned the region for the exceptionally cold conditions of the 1992 New Zealand winter.

The anomalous atmospheric and oceanic conditions in the south-west Pacific during this period could be related to the prolonged El Niño-Southern Oscillation (ENSO) episode which began in early 1991. Draining of the tropical Pacific upper ocean volume from west to east has been associated with ENSO events in the past (Wyrtki, 1979; Kessler and Taft, 1987). The temperature gradient across the tropical Pacific implies a subsequent eastward transfer of heat. The eastward zonal equatorial currents (the North and South Equatorial Counter Currents) generally increase in strength and width during ENSO events (Donguy and Dessier, 1983; Meyers and Donguy, 1984). Moreover, the width and strength of the westward South Equatorial Current (SEC) decreases, and the flow direction may even occasionally reverse during ENSO-related westerly wind bursts (McPhaden *et al.*, 1992). The SEC feeds the southward flowing EAC. Hence, the decreased transport of the EAC during early 1992 is a consequence of the redistribution of mass and heat that takes place from west to east in the tropical Pacific under the ENSO conditions. The implication for the Tasman Box is that interannual fluctuations, such as ENSO, may play an important part in regional climate variability.

There are other possibilities for the anomalously cold oceanic conditions in the south-west Pacific during winter of 1992. Stronger than usual westerly winds with some southerly component persisted in the records at coastal sites along New Zealand's North Island (Thompson and Basher, 1993) and in the Auckland Airport meteorological data during late August–early September 1992. Were these winds cold enough or strong enough to produce the deep mixed layers observed in the quarterly time series of temperature observations off Auckland? To answer this question we look to variability in the atmospheric meridional heat transport of the region.

Hourly meridional wind (v) and air temperature measurements (T) have been collected at Auckland Airport since 1965. The daily meridional heat flux (v′T′) of 1992 is shown in Figure 6. Monthly climatological mean (dashed line) and standard deviation (vertical bars) calculated from the 1965–93 record are also shown. At the beginning of September 1992 a significant event occurs where v′T′ changes sign from negative to positive. Both extremes lay outside the climatological standard deviation for that month. A positive value of v′T′ implies that colder air is associated with more northerly winds, while a negative value of v′T′ implies colder air is associated with more southerly winds. While the converse of this is also true, in this case T′ is strictly negative (cooler than average) for the time period, and it is v′ that changes sign (from southerly to northerly). It appears that while there was a significant atmospheric meridional transport of cold air in September 1992, it was not the only significant cooling event in the v′T′ record. Anomalous atmospheric heat transport was also observed in other months which had no subsequent effect on temperatures measured by the XBT time series. It does not appear that the enduring negative anomaly in temperature is caused by southerly winds.

Another possiblity is that stronger winds may have increased the latent heat loss from the ocean to the atmosphere during this period, resulting in a cooler sea surface layer. Here, it is the magnitude of the wind that is important and not the direction. The ECMWF latent heat loss measurement for September 1992 was not significantly different from that of

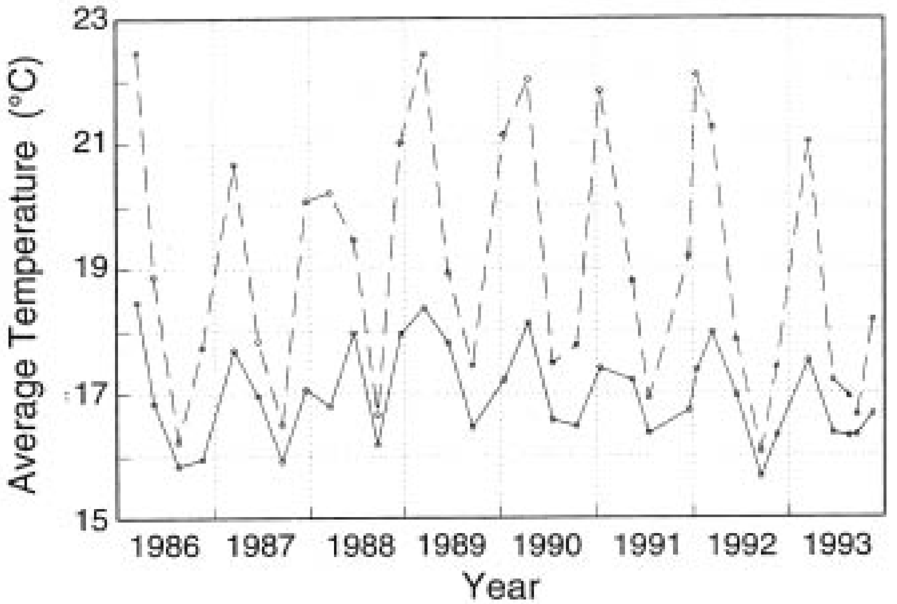

Figure 4. Sea surface temperature (dashed) and vertically averaged temperature for the top 200 m (solid) spatially averaged between 30°S and 35.5°S along the Auckland–Fiji track. Circles indicate the month of each cruise.

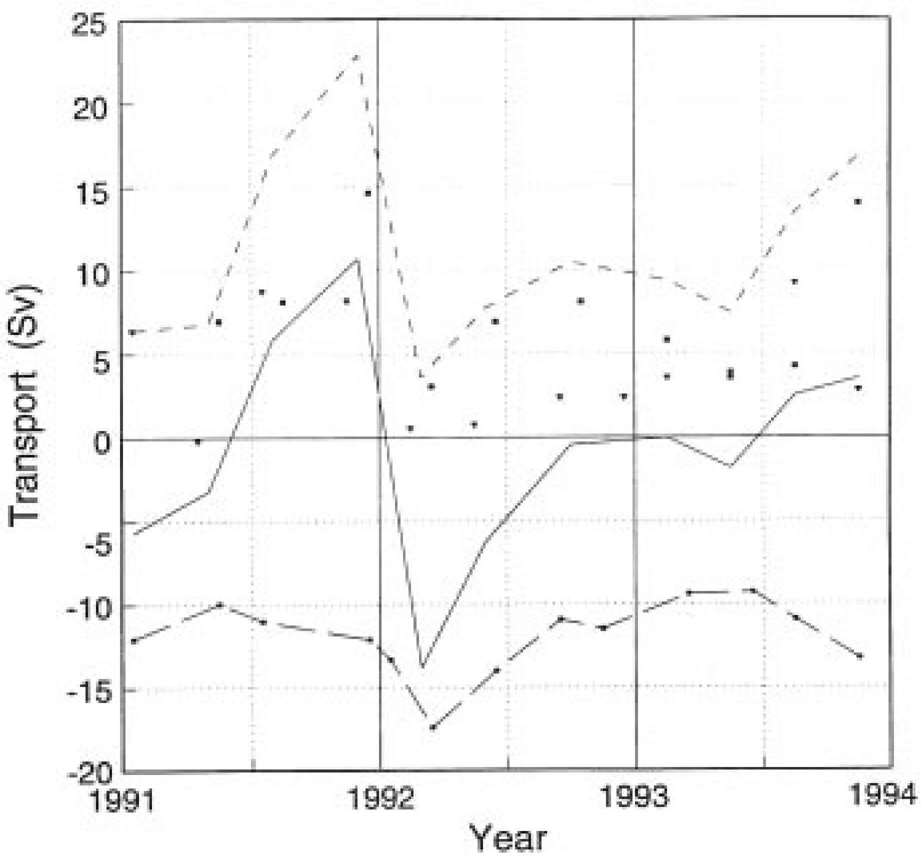

Figure 5. Time series of geostrophic transport relative to 800m, of waters warmer than 12°C for the Tasman Box (solid line). Transport values for each Brisbane–Fiji cruise (solid squares) and Sydney–Wellington cruise (solid triangles) are added together as inflow iinto the Tasman Box (short-dashed line). Outflow from the Tasman Box is across the Auckland–Tiji transect (long-dashed line).

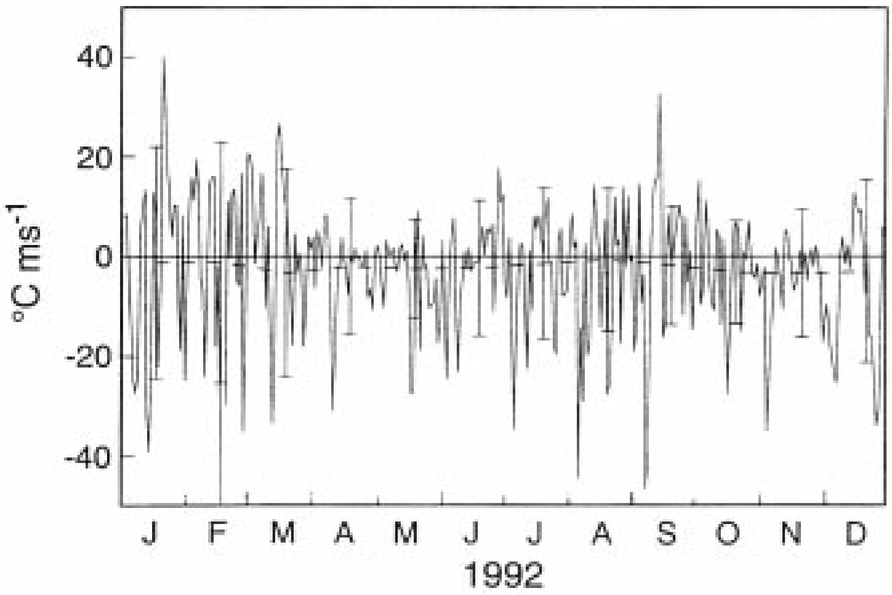

Figure 6. Daily meridional heat flux (v'T') at Auckland Airport during 1992. The monthly mean (dashed line) and standard deviation (vertical bar) for the 1965–93 time series are also shown.

the previous September when no anomalous oceanic cooling was observed.

The magnitude and vertical extent of the cold anomaly were too great to be due solely to variability in the air-sea heat and momentum fluxes on time scales of a few days. A change of about 150 W m^{-2} in ocean heat storage over 3 months would produce a 1.5°C cooling in the top 200 m of the ocean. This is nearly equivalent to the observed annual range in the air-sea heat exchange alone for the entire Tasman Box area.

Conclusions

This study shows the influence of ocean circulation and associated heat transport in short-term midlatitude climate fluctuations. Few investigators have studied the zonal ocean transport of heat in the midlatitudes, both in terms of the mean and variability of the transport estimates, and redistribution in the subtropical gyre. Here geostrophic divergence estimates indicate that warm surface waters were drained eastward, and probably replaced by an upward flux of the deeper colder water below. The heat flux by the ocean currents out of the region in early 1992 was a precursor to the cold weather experienced in the south-west Pacific during winter. Such an explicit example of fluctuations in ocean heat transport playing an influential role in regional climate variability emphasises the need for continued monitoring of upper ocean thermal structure in the subtropics. Repeat high-density XBT sampling in this region can help improve the mean and time-varying statistics of the mass and heat transport processes of the south-west Pacific subtropical gyre.

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Repeat Hydrography Programme for Line PR6

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The Line P (WOCE Line PR6), Station P (WOCE Station PRS1) programme is one of the longest ocean time series in existence (Figure 1). Canada has had vessels visiting Station P for meteorological observations since 1950, and began oceanographic measurements in 1956. Over 4000 profiles of temperature and salinity have been taken at Station P to date (Tabata and Weichselbaumer, 1992). Through time, sampling has been modified as new technologies improved oceanic measurements. In 1952, bathythermograph casts began and continued until 1981. By 1956, hydrographic casts routinely collected water samples to 1200 m depth. Not until 1960 were these casts extended to a full depth of 4200 m. In 1969, STD (CTD) casts accompanied water sampling routinely.

The full time occupation of Station P with weather-ships ended in June 1981, when satellites started providing reasonable means of weather forecasting, and the expense of maintaining two vessels could not be justified. Since that time, 2 to 6 cruises yearly along Line P have provided information on seasonal and inter-annual variability down to 4200 m off the Canadian west coast.

In 1991, the Institute of Ocean Sciences started modifying its sampling strategy and procedures to meet WOCE criteria (our motto through this has aptly been "For Better or for WOCE"). Our research vessel, the John P. Tully has since been outfitted with a larger A-frame, a more powerful bow thruster for holding station, an ADCP system and improved lab space. As we head into 1994, we now possess a newly instrumented rosette-winch system that is capable of deep ocean sampling to 6000 m.

Principal Investigators involved in Line P cruises include:

C.S. Wong, IOS, carbon transport (WOCE and JGOFS)
H.J. Freeland, IOS, ocean circulation (WOCE)
P.W. Boyd and P.J. Harrison, University of B.C., productivity (JGOFS)

Results in this article are the recent findings of these research groups, and are largely in preparation for publication.

The Line P time series has produced important data sets that permit us to understand the impact of global perturbations such as El Niño/La Niña oscillations and the increase of greenhouse gases. We have learned that warm water intrusions onto the B.C. coast displace salmon stocks, causing them to feed in different areas and alter their spawning routes. The flow of equatorial water to the north is also associated with unusually high fluxes of particulate organic carbon to the deep ocean.

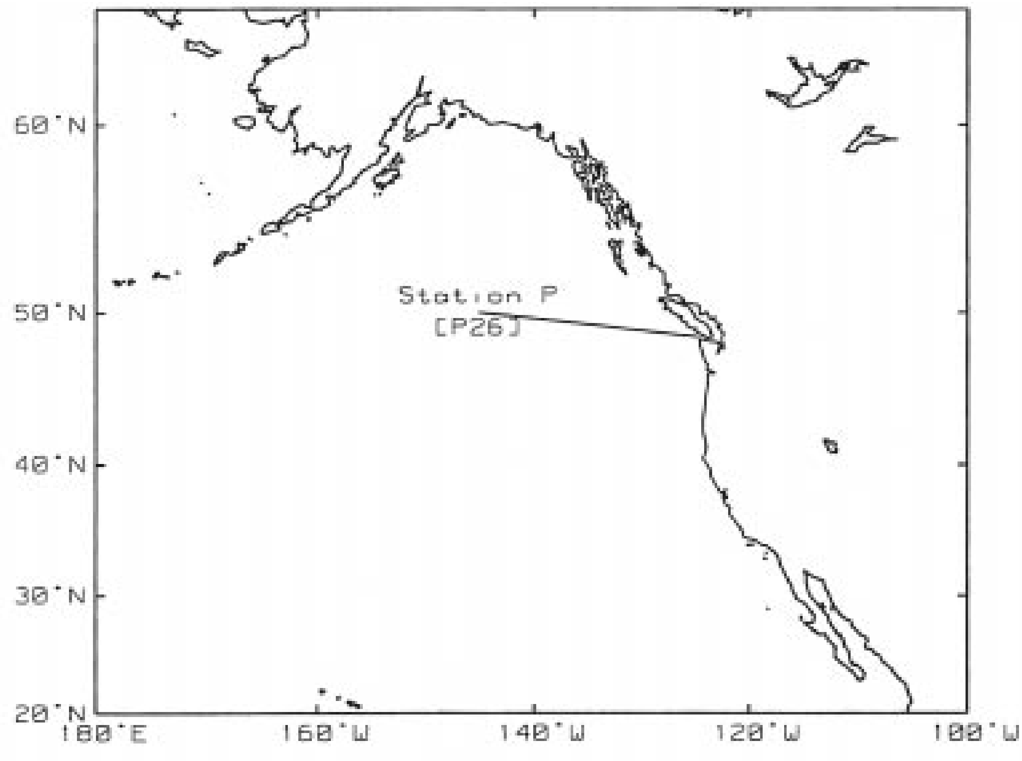

Figure 1. Location of Line P and Station P in Northwest Pacific Ocean.

Line P cruises support JGOFS programmes in the N.E. Pacific. Recent controlled growth experiments have provided strong evidence that iron limits diatom growth at Station P (P.W. Boyd). Also, the Climate Chemistry group at IOS has been using trace metal clean procedures to re-evaluate the productivity of the N.E. Pacific at

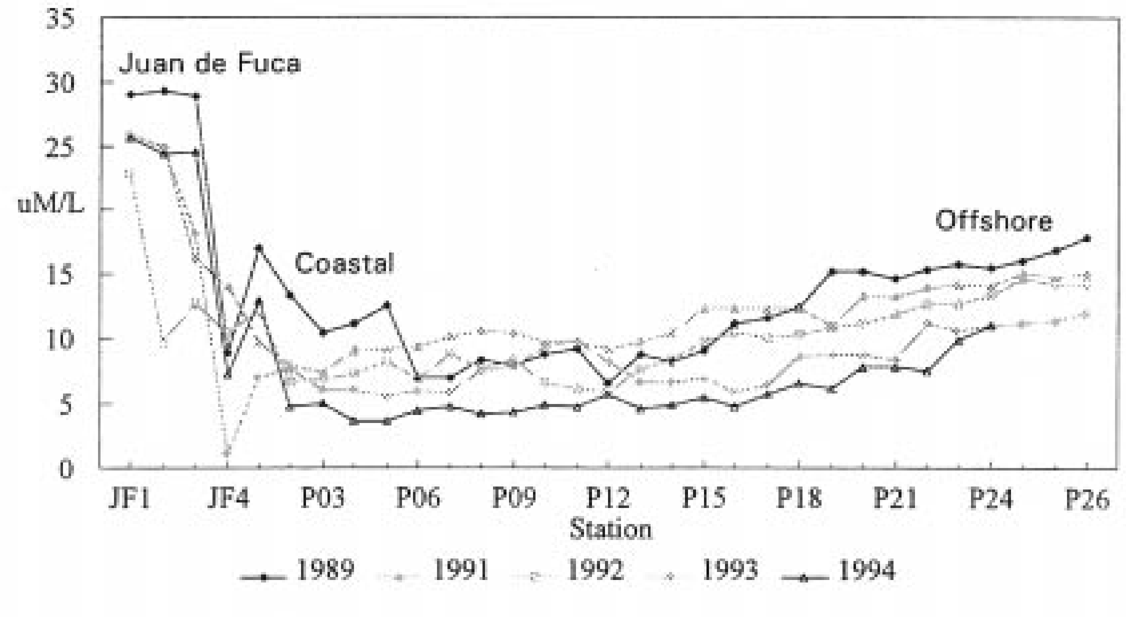

Figure 2. Late winter surface nitrate concentrations along Line P.

which could stimulate primary production.

Sea surface temperature at Station Papa shows a small, but significant, warming trend at the rate of about 1.9 ±1.2°C per century (trend ± 95% confidence level). However, it also shows a large and extremely significant declining trend in salinity of -0.47 ±0.18 psu/century. These translate into a steady decline, over the last 39 years, in surface σ_t of -0.42 ±0.31 σ_t units/century. If we assume that deep densities are remaining more-or-less constant then provided the energy input from the wind remains constant, the depth of the mid-winter surface mixed layer must decrease.

We have estimated the depth of the mid-winter mixed layer from all January, February and March observations at Station Papa by fitting a simple mixed layer model to the top 300 metres of water column.

140 mg C m^{-2} d^{-1}, more than double the estimates from the 1960s.

A recent trend to lower surface nutrients is currently being monitored. Over the past 5 years, winter nitrate levels along Line P have steadily decreased to 54% of February 1989 values (Figure 2).

Lower winter nitrate can be the result of increased phytoplankton growth, reduced storm activity, stronger density gradients in the upper ocean (temperature increase/salinity decrease), or increased flow of nutrient-poor water (decreased flow of nutrient-rich water) into the region. Previous nutrient decreases have been associated with El Niño events, so this current trend may also be the result of successive weak El Niños in 1992 and 1993.

Certainly, we have measured greater carbon uptake by phytoplankton in the past decade compared with the 1960s. However, we believe this is more a result of improvements in procedures, especially in reducing trace metal contamination of incubated waters. Still we cannot rule out an increase in iron transport into this area

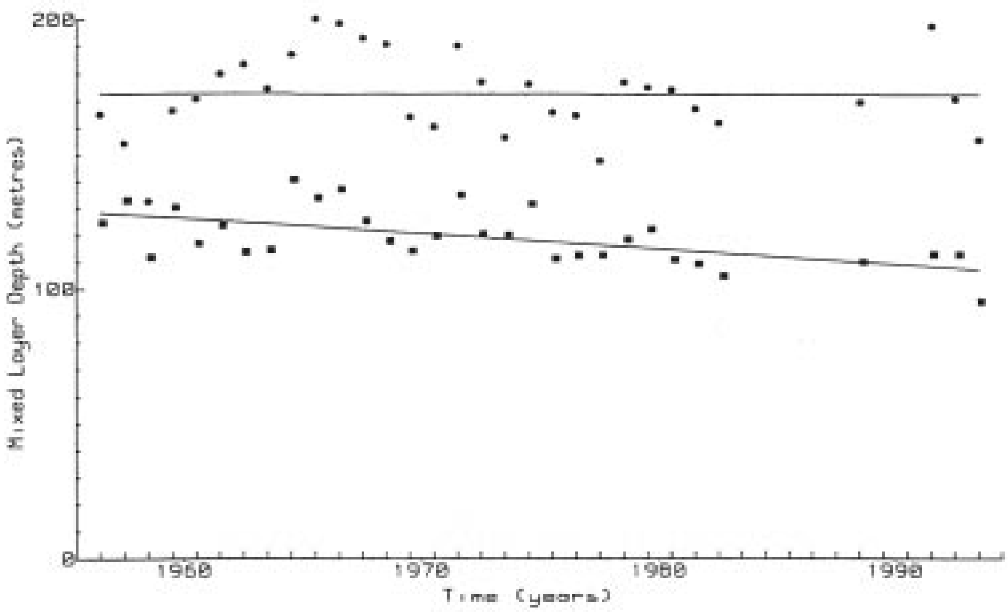

Figure 3. Mixed layer depth (squares) and an estimate of work required to increase the mixed layer depth (dots) at Station P.

In the early years there are frequently several observations per winter, in the later observations usually only a single observation. Wherever appropriate an average mid-winter value is plotted (Figure 3). There has been a strong and statistically significant decrease in mixed layer depth over the history of the Station Papa observations. The upper mixed layer has apparently decreased in depth from 130 m in the mid-1950s to about 105 m at the present time, a rate of decline of 58 ±29 m/century. The 95% confidence interval has been computed assuming that each mid-winter mixed layer depth is independent of the previous year's estimate. The dots represent, with arbitrary vertical scale, the product of mixed layer depth and the σ_t contrast across the base of the mixed layer. This is proportional to the extra work (dW) required to increase the mixed layer depth by an amount dz. Apparently, the work required to produce a mixed layer has remained constant, thus we can attribute the shallowing of the winter time mixed layer depth to the decrease in surface buoyancy.

As the mixed layer shallows, individual phytoplankton cells will be cycled by turbulence up and down through steadily shallower layers and so will spend increasingly larger fractions of their lives in the photic layer. Thus we expect an increase in plankton productivity due to the shallowing mixed layer depth. Such an increase has been reported by Brodeur and Ware (1992). As the plankton increase, the demand for nutrients must increase. However, as the density contrast across the base of the mixed layer increases, the supply of nutrients from the deep ocean must decrease. Hence we provide an explanation for the decrease in the nutrient loading at Station Papa.

References

Brodeur, R.D., and D.M. Ware, 1992. Long-term variability in zooplankton biomass in the subarctic Pacific Ocean. Fish. Oceanogr. 1: 32–38.

Tabata, S., and W.E. Weichselbaumer, 1992. An update on the statistics of hydrographic/CTD data taken at Ocean Station P, May 1956–September 1990. Can. Data Rep. hydrogr. Ocean Sci. 107: 75pp.

First Edition of the WOCE Data Handbook Issued

The first edition of the WOCE Data Handbook was released by the WOCE Data Information Unit during May 1994. The handbook provides information on the operation of the components of the WOCE data management system:

- Data Assembly Centres – DACs,
- Special Analysis Centres – SACs,
- World Data Centres – WDCs,
- Data Information Unit – DIU, and
- Satellite data arrangements,

with particular attention given to identifying modes of data distribution.

The Handbook is a source book to discover:

- what datasets are available from the WOCE field programme and supporting measurements; and
- how to get access to them.

Inventories of the data collected and products of general interest generated from WOCE data are included in the handbook. The inventories and associated figures will be updated on a regular basis. (Only updated pages will be re-issued, the Handbook is in looseleaf form.)

The Handbook is a guide, not a data source. It does not provide full details of specific WOCE field programmes. If more details are needed, the on-line information system, OCEANIC, must be used in conjunction with the Handbook. An introduction to OCEANIC and the information services of DIU are given elsewhere in this Newsletter and in the Handbook. Information contained in the Handbook is, however, sufficiently complete to allow users to go directly to the data centre (DAC, SAC or WDC) holding and issuing datasets of interest. In some cases, for example soon after a particular field project is completed, the user may be required to go directly to the responsible PI to obtain data or for permission for their release by a centre. While PIs have proprietary rights for two years, they are encouraged by WOCE to share their data early, particularly when recipients of data are willing to cooperate in studies and co-author results.

The Handbook and its updates rely on the readiness of PIs and DACs to work with the WOCE Data Coordinator (presently Bert Thompson) at the DIU in keeping its contents accurate and comprehensive. Please inform the DIU of any additions, corrections or improvements that you can suggest.

Over 300 copies of the Handbook have been issued and DIU is considering the possibility of a second full issue when the first updates are issued later this year. Anyone interested in receiving a copy at that time should notify DIU at:

College of Marine Studies
University of Delaware
Lewes, DE 19958, USA
Internet: woce.diu@delocn.udel.edu
Omnet: WOCE.DIU

The Handbook is also available from DIU electronically on World Wide Web.

WOCE Data Information Unit (DIU) On-line Gopher and World Wide Web Information Systems

Information about the status of the WOCE Field Programme is available on-line from the WOCE Data Information Unit (DIU). If you have a computer connected to the Internet, you may access this system, called OCEANIC (Ocean Information Center), at any time.

Recently, the DIU has added some new forms of presentation to OCEANIC and increased the options for on-line access. There are three different forms of presentation. The original presentation of OCEANIC is accessible through a telnet session over the Internet. This basic system focuses on WOCE information and an international research ship schedule. The newer versions use the Gopher and World Wide Web systems to present the above information as well as information about the TOGA/COARE experiment and to provide direct links to other ocean data and information services.

The World Wide Web and Gopher systems allow users to access easily various types of data in various locations around the world in a seamless fashion. For example, a user can first read about oceanographic data at Scripps, and then actually jump directly to Scripps to see the data. In Gopher these 'links' are made through menu choices. On the Web, these 'links' are made by using the mouse to select a highlighted phrase. This linking capability allows data to remain in the hands of the scientist who knows them best, while allowing the user to access them without difficulty.

Here's how you can sign on to OCEANIC:

1. Gopher

A. For users with Gopher software

If you have Gopher software on your computer type **gopher gopher.cms.udel.edu**.

We recommend using Gopher on your own computer rather than accessing one of the public Gopher systems. You can use features of your own computer and you should have better response time.

B. For users without Gopher software

If you do not have Gopher available you may use one of the public Gopher systems listed below in Table 1. These may be somewhat restricted in function, but will provide the necessary basics. Each public Gopher site's menu is slightly different, but most have a similar menu tree to reach OCEANIC. Look for a reference to "other Gophers" or "other internet resources" and work your way through the geographic hierarchy (Gopher servers/North America/ USA/Delaware) to link to OCEANIC.

Using Table 1, choose the public Gopher site closest to you. Telnet to that site, using the login name specified. For example, if you live in the US, type **telnet gopher.msu.edu**, and at the login prompt, type **gopher**.

Table 1. Public Gopher Sites

Telnet to	IP Number	Log in as	Menu selections to reach OCEANIC	Area
gopher.msu.edu	35.8.2.61	**gopher**	Network & Database Resources -> Internet Resources by Type -> Gopher Servers -> North America -> USA -> Delaware -> OCEANIC	N. America
gopher.ebone.net	192.36.125.2	**gopher**	Other Gopher & Info Servers -> USA -> Delaware -> OCEANIC	Europe
i**nfo.anu.edu.au**	150.203.84.20	**info**	Worldwide Networked Info Servers -> Search for Gophers by Name or Internet Address: OCEANIC, Univ. of Delaware	Australia
tolten.puc.cl	146.155.1.16	**gopher**	Otros servidores de Gopher en el mundo -> North America -> USA -> Delaware -> OCEANIC	S. America
gan.ncc.go.jp	160.190.10.1	**gopher**	Other Gophers etc. -> World wide gopher list (mirror) -> North America -> USA -> Delaware -> OCEANIC	Japan

Table 2: Public World Wide Web Sites

Telnet to	Log in as	Menu Selections to Reach OCEANIC	Area
info.cern.ch	**www**	Places to Start Exploring (3) -> By Subject (1) -> Oceanography (71) -> The Ocean Information Center, Delaware (19)	Europe
ukanaix.ce.ukans.edu	**www**	By Subject -> Oceanography -> WWW -> The Ocean Information Center, Delaware	N. America
www.njit.edu	**www**	Once signed on select **Go** and enter the following address: **http://www.cms.udel.edu/**	N. America
vms.huji.ac.il	**www**	Easy to Use -> Information by Subject (2) -> WWW Subject Catalog (9) -> Oceanography (71) -> WWW (3) -> The Ocean Information Center, Delaware (19)	Israel

No password is required. The table shows the menu selections you must follow to reach OCEANIC.

2. World Wide Web (WWW)

A. For users with a World Wide Web browser

If you have World Wide Web browsing software (such as Mosaic, Lynx, Cello) on your computer, to reach OCEANIC you must connect using the URL (Uniform Resource Locator) http://www.cms.udel.edu/. How you do this depends on the software you are using. For example, if you are running Mosaic, select **File/Open URL** and enter **http://www.cms.udel.edu/**.

We recommend using a World Wide Web browser on your computer rather than accessing one of the public sites. Local software can use features of your local computer and should give you better response.

B. For users without a local World Wide Web browser

If you do not have a World Wide Web browser, you may use one of the public sites listed in Table 2. These may be somewhat restricted in function but will provide you the basic links to move through the Web. As with Gopher, each public site's menu structure differs slightly, but most have a similar menu tree to get to OCEANIC at the University of Delaware.

Using Table 2, choose the public web site closest to you. Telnet to that site, using the login name specified. (Note that these sites require a minimum of VT100 compatibility). For example, if you live in the US, type **telnet www.njit.edu**, and at the login prompt, type **www**. No password is required. See below for the menu selection you must follow to reach OCEANIC.

3. OCEANIC for users without Gopher or WWW access

You can also reach OCEANIC over the Internet, over SPAN, via Omnet or by direct dial telephone. If you can, we recommend you use the Gopher or World Wide Web systems for their enhanced capabilities.

Over the Internet:
- **telnet delocn.udel.edu** (or **telnet 128.175.24.1**)
- Username: **INFO**
- No password required

Over SPAN:
- Type: **set host DELOCN**
- Username: **INFO**
- No password required

Via Omnet:
- Log on to your Omnet account
- Select **Backdoor**
- Choose OCEANIC from the menu (currently item #6)
- This will take you directly into OCEANIC
- No password required

Direct Dial:
- Dial: (302) 831-6435 (6150, 6152)
- (up to 14.4K bps, set at 8,1,N)
- When the connection is established:
- UDelnet>**delocn**
- Username: **INFO**
- No password required

If you have questions on accessing OCEANIC, please do not hesitate to write or call. You can reach us at:

The Ocean Information Center
College of Marine Studies
University of Delaware
700 Pilottown Road
Lewes, DE 19958
tel: (302) 645-4278
fax: (302) 645-4007
Internet: woce.diu@delocn.udel.edu
SPAN: DELOCN::WOCE.DIU
Omnet: WOCE.DIU/Omnet

Upper Ocean Thermal Data Availability

WOCE has a well defined structure for the distribution and quality control of upper ocean thermal data (primarily from XBTs). Much of the system is now working, though somewhat behind schedule for some of the data. Data undergo basic quality control (QC) checks at various national centres, then detailed scientific quality control and flagging at regional centres which use their local expertise to assess the data. The regional Data Assembly Centres or DACs (AOML for Atlantic, CSIRO for Indian, and SIO for Pacific) produce high quality data sets and will also generate research-quality products.

The data QC system is still evolving, but some data sets are already available to the scientific community. The table below illustrates data sets which are presently available, and the anticipated schedule for those which are not.

For information on how to obtain these data sets, plus details of the QC system and processes, please consult the WOCE Data Information Unit.

Data Type	Level of QC	Collection Period	When Available	Where Available
Real-time data (inflexion points) transmitted over the Global Telecommunication System (GTS)	Basic checks only	Monthly (1990 on)	Now	MEDS*, NODC*
Delayed Mode data (high resolution profiles submitted by the originators)	Basic checks only	1990 1991 1992 1993	Now Now November 1994 February 1995	NODC & GSTDC* NODC & GSTDC NODC & GSTDC NODC & GSTDC
High resolution and inflexion point data (GTS and delayed mode)	Full scientific	1990 (Atlantic) 1990 (Indian) 1990 (Pacific) 1990 (all oceans) 1991 1992 1993	Now October 1994 Fall 1994 Fall 1994 July 1995 July 1995 August 1995	AOML DAC CSIRO DAC SIO DAC NODC & GSTDC NODC & GSTDC NODC & GSTDC NODC & GSTDC

* MEDS is the Marine Environment Data Service of Canada; NODC is the National Oceanographic Data Centre of USA; GSTDC is the Global Subsurface Thermal Data Centre in Brest, France.

The GEBCO Digital Atlas (GDA): Now Available on CD-ROM

A CD-ROM of the General Bathymetric Chart of the Oceans (GEBCO) Digital Atlas has recently been published by the British Oceanographic Documentation Centre on behalf of the Intergovernmental Oceanographic Commission (IOC) of UNESCO and the International Hydrographic Organisation (IHO). It includes a seamless, global, digital set of the GEBCO basic contours (*i.e.* 200 m, 500 m and at 500 m intervals thereafter) with contours at intermediate depths also included in some areas, where available. The CD-ROM is accompanied by a floppy disk containing the GDA Software Interface and an extensive Supporting Volume describing the activities of GEBCO and providing a User Guide to the software.

The GDA CD-ROM contains:

- Digitized bathymetric contours, coastlines and trackline control from the GEBCO Fifth Edition published at a scale of 1:10 million;
- Digitized bathymetric contours and coastlines from the First Edition of the International Bathymetric Chart of the Mediterranean published at a scale of 1:1 million;
- A set of digital global coastlines, based on the US Defence Mapping Agency's World Vector Shoreline, at a range of scales from 1:43 million to 1:250,000;
- A trackline inventory of the digital echo-sounding data held at the IHO Data Centre for Digital Bathymetry as of December 1993;

- A digital set of geographically referenced feature names including the IHO/IOC Gazetteer of Geographical Names of Undersea Features and a specially prepared list of oceanic islands;
- A digital version of the Third Edition of the Echo-Sounding Correction Tables.

The GDA Software Interface provides a powerful and user friendly tool kit which includes facilities for selecting, interrogating, visualising, overlaying and exporting data from the GDA. It has a very low learning overhead enabling the user to zoom into any geographic area of interest at will. Contours, coastlines and tracklines can be displayed at a choice of 5 projections and the names of undersea features and oceanic islands can be queried interactively. Screen images can be directed to the user's printer or stored as a PCX or GEM image for use in desktop publishing software. Selected contours, coastlines and tracklines can be exported in vector form as labelled streams of geographic coordinates, either in DXF format or as a simple flat ASCII file.

To run the Digital Atlas you will need an IBM PC (or compatible) with a VGA colour display, a CD-ROM drive, a 3.5" floppy disk drive and a hard disk with at least one Megabyte of free space in which to install and run the software. The software is designed to run under DOS 3.0 or later, and requires about 500K of free RAM. A mouse (Microsoft compatible) is highly desirable but not essential. The contours, coastlines and tracklines (except for the World Vector Shoreline) are also stored on the CD-ROM in a simple ASCII file format directly accessible to the user without the need to use the interface software.

For coloured brochure and order form, please contact:
GEBCO Orders
British Oceanographic Data Centre
Proudman Oceanographic Laboratory
Bidston Observatory, Birkenhead
Merseyside, L43 7RA, UK
Fax: 44-51-652-3950
email: bodcmail@unixa.nerc-bidston.ac.uk

WOCE Provides the Stimulus for a New Oceanography Textbook

Matthias Tomczak, Flinders Institute for Atmospheric and Marine Sciences, The Flinders University of South Australia, Adelaide, SA 5001

In 1985, I was struggling as the only physical oceanographer at the University of Sydney to establish a curriculum in oceanography. There were many good textbooks but none that comprehensively covered a key aspect of the curriculum. As a deep ocean observationalist, I wanted to include a course on regional oceanography, which I define as the study of the large-scale ocean circulation and its water masses. However I wanted the study to go beyond geographical description to include at least some explanation in terms of basic geophysical fluid dynamics. A measure of the success of such a course would be that all students, regardless of their level of knowledge in geophysical fluid dynamics could describe the science behind the oceanographic components of the World Climate Research Programme. They should see the WOCE Hydrographic Survey as a station layout based on modern ideas of ocean dynamics. They would see the network of current meter moorings in terms of western boundary and equatorial wave guide dynamics and should understand the measurement strategy of TOGA.

Initially I had to tell my students that they had to live without a textbook but eventually Stuart Godfrey and I became equally convinced that there was a real need for a new textbook on regional oceanography.

This is the background to *Regional Oceanography: an Introduction* by M. Tomczak and J.S. Godfrey (1994), Pergamon Press, Oxford. We believe that we have produced a text that allows students to understand the principles of oceanic circulation and water mass formation and recognize them in regional observations.

The first five chapters establish the theoretical foundations, using few equations and distilling the essentials into easily remembered “rules” (*e.g.* the thermal wind relation, expressed in words rather than symbols). The next eleven chapters discuss the oceanic circulation and water masses in geographic detail and explain them in terms of physical principles and application of rules learnt at the beginning. The last three chapters discuss ocean/atmosphere interaction.

It has been satisfying to see students with only high school mathematics interpret an XBT section across the equatorial Pacific Ocean in terms of current direction and strength, identifying the components of the equatorial current system and enjoying it. WOCE made it happen, because WOCE is the strongest manifestation of the present era of regional oceanography.

Regional Oceanography: an Introduction has been in bookstores since February. Unfortunately the book contained some serious printing errors and so Pergamon Press is now delivering the book with an extensive errata sheet. Anyone who bought a copy before the errata sheet was included can obtain one from me at Flinders University, GPO Box 2100, Adelaide, South Australia 5001, faxing me at +61-8-201-3573, or by email mattom@es.flinders.edu.au.

An Announcement and an Enquiry (both with respect to scientific publications)

Peter Saunders, WOCE IPO

If you are looking for a collection of WOCE scientific references, where do you search? If you are a researcher from the USA you might look in WOCE NOTES which has a page devoted to recent WOCE bibliography. If you are accustomed to search the files of the Data Information Unit (DIU), Delaware, on internet via telnet, Gopher or Mosaic, you will also be aware that the complete list of such references exists in electronic form in that one location. But the astute amongst you will have noted that this represents purely a US National effort, and, surprisingly to some, research does take place elsewhere. For instance countries outside of the USA will be responsible for one-half of the one-time survey cruises, which represents the pinnacle of hydrographic experimental effort in WOCE.

So where do you look for an *international* collection of WOCE scientific references? The answer is that shortly you will find it on the DIU. At the instigation of John Gould, the Director of the International Project Office (since the beginning of this year), Pauline Simpson, the Librarian at the Institute of Oceanographic Sciences Deacon Laboratory, Wormley, is presently constructing a list of such references. This list will be based initially on the 650 WOCE references held by the IOSDL library, will be ordered by country and subsequently augmented by national WOCE committees. With the permission of Dr Ferris Webster, the director of the DIU, the list will be placed in the public files of the DIU and periodically updated. It is planned for the initial bibliography to be at the DIU within the next few months.

Such a list of publications will help both managers and researchers and will indicate where oceanographic science was *one to two years ago*, the interval between completion and publication of a manuscript. In this interim period, draft manuscripts circulate amongst friends and get copied by their friends etc., sometimes even reaching Ph.D students! Nobody seems to mind this informal circulation of information and ideas which could in principle be pirated and rapidly published elsewhere. Except that most people are honourable and, besides, the real author has always got a head start. So why not circulate this information freely and widely? WOCE science should benefit greatly from the speedy exchange of ideas and new observations.

My suggestion is that after submitting an article to a journal, the author would (electronically) mail a copy of the title, abstract, author, (email) address, keywords and journal where submitted etc. to the DIU, who would post it amongst a collection of similar abstracts, namely from *manuscripts under consideration for publication*. The abstract would be automatically removed when the title appeared in the WOCE list of published articles, or the DIU was advised it was published, or after two years had elapsed (to ensure the removal of dead wood), or if the author decided to withdraw it. In the latter case no questions would be asked. Such a collection would be entirely voluntary, entirely without obligation, and would purely communicate ideas and information more rapidly and systematically. (Make use of the information superhighway? GROAN – Ed.) Anyone could access the collection and, if interested in a particular item, ask the author for a pre-print.

If you think this idea might work and you would be willing to communicate an abstract (or two) let me know (email: pms@unixa.nerc-wormley.ac.uk). Please do not send the abstract. If there is a deathly silence I will know what to do! Some of you will wonder about the copyright issue. We are investigating this problem and clearly if it proves an insuperable barrier we will have to abandon the idea. But we do not expect this.

CLIVAR Status Report

Arnold Gordon, CLIVAR SSG Chairman, Lamont Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA

The planning committee that first considered the science structure of CLIVAR in 1992 defined two foci based on time-scale of climate variability: CLIVAR-1 dealing with seasonal to interannual climate variability and predictability and CLIVAR-2 with the decadal to centennial scales. In mid-1993 the newly established CLIVAR SSG developed two scientific thrusts for each of the foci. However, the SSG recognized that many programme elements do not lend themselves to simple separation by time scales. For example, should the study of decadal variability of the ENSO signal fall under CLIVAR-1 or 2? And, ocean variability with predominant low frequency characteristic may have climatologically significant interannual scales or may at least be influenced by higher frequency phenomena. In addition, some of the models which will be used for climate predictability will have an atmospheric component that is essentially the same as that used in medium range weather forecasting and not very different to that used in extended climate integration. Similarly, the ocean components of the models used for interannual predictability and extended climate integration will have common modules. With this in mind the WCRP's Joint Scientific Committee in March 1994 approved a proposal that the thrusts be moved from under the foci umbrella to stand on their own, though clearly each is primarily (though not exclusively) associated with a different range of scales. The elimination of the timescale separation allows for a more logical grouping of scientific pursuits and encourages a more unified approach to climate investigations on all time scales.

The four initial science thrusts of CLIVAR are:

1. predictability and prediction of the low-latitude coupled system and its links to the extra-tropics;
2. the role of the monsoons in the global climate system;
3. variability of the thermohaline circulation;
4. the physical climate response to anthropogenic forcing, including sea-level change.

Each would involve modelling, assembly and diagnosis of proxy and historical climate data and systematic observational activities and process studies, as appropriate.

The objectives for the overall CLIVAR programme as proposed by the JSC are:

1. To describe and understand the physical processes responsible for climate variability and predictability on seasonal, interannual, decadal and centennial time scales, through the collection and analysis of observations and the development and application of models of the coupled climate system, in cooperation with other relevant climate-research and observing programmes.
2. To extend the record of climate variability over the time scales of interest through the assembly of quality-controlled paleoclimatic and instrumental data sets.
3. To extend the range and accuracy of seasonal to interannual climate prediction through the development of global coupled models.

CLIVAR and WOCE

Thrust No. 3 "variability of the thermohaline circulation" deals with heat and freshwater fluxes associated with the global ocean circulation and its relationship to the climate system, a natural follow-on to the WOCE snapshot 'mean circulation' view of the ocean. CLIVAR will build on the effective infrastructure developed by WOCE, and continue WOCE science initiatives related to ocean variability, which is likely to include upper ocean monitoring; repeat meridional heat/freshwater flux sections; satellite altimetry; use of new technologies for ocean monitoring; continued use of chemical tracers to unravel the time scales of ocean circulation; and study of specific climate related ocean phenomena and processes, including inter-ocean fluxes and water mass formation processes.

CLIVAR SSG-3 will meet in the last week of September 1994 to produce the CLIVAR Initial Science Plan. Before then we plan to solicit comments on a draft science plan, which will be distributed in June or early July 1994.

WOCE Results at the IUGG/IAPSO XXI General Assembly, Boulder, Colorado, 2-15 July 1995 – A Call For Papers

As part of the IAPSO programme for this assembly, 4$^1/_2$ days have been reserved for symposium PS-Ol, 'The Large Scale Ocean Circulation' which aims to present new observational, modelling and theoretical results that diagnose the present-day large-scale circulation of the World Ocean, and the transports of mass, heat and the substances of the ocean. This symposium is happening at a particularly important moment in the lifetime of the WOCE experiment, when a vast range of new results first become available for presentation. 1994 would have been too early with much data only recently-recovered, while by 1996, many of the most exciting new data sets will already have been published. Thus although PS-O1 is certainly not restricted to the discussion of WOCE and its results, 1995 is a particularly apt time for the first display of much of the new WOCE material.

The component sessions of PS-Ol have been designed with this in mind:

- Session 1 is subtitled *The Abyssal Circulation*. Bob Dickson is the Corresponding Lead Convenor for the whole of PS-Ol and the Convenor of this particular session;
- Session 2 is entitled *The Great Trans-Ocean Sections* with Harry Bryden as Co-Convenor;
- Session 3 will describe *The New Lagrangian Data Set* with Russ Davis, SIO, as Co-Convenor;
- and in Session 4, Eberhard Fahrbach, AWI, will act as Co-Convenor for a programme on *The Circulation of Polar and Sub Polar Seas (Arctic and Antarctic)*.

Each session will be allocated up to one day for its presentations which will consist of a Keynote Overview, Papers and Posters; to preserve what we hope will be a spectacular array of new results, we are discussing the possibilities of publishing the best of the presentations in book form. I will be keeping you up to date with the planning as it develops. Please note that the programme for each session will be selected by the Convenor and relevant Co-Convenor on the basis of abstracts received, and the fact that abstracts should be submitted to the Corresponding Lead Convenor in the first instance:

Bob Dickson
MAFF Fisheries Laboratory
Lowestoft, Suffolk NR33 0HT
England.
Tel: 44-502-562244(lab) or 524282 (desk)
Fax: 44-502-513865
Twx: 947470 lowestoft
Omnet: MAFF. LOWESTOFT

WOCE IPO at Oceanology International ’94

Ilse Hamann, WOCE IPO

The WOCE IPO was represented this spring at Oceanology International ’94, the largest marine science and technology event worldwide. The displays on the WOCE stand showed key elements of WOCE research. The cost of the exhibition was partly covered by contributions from commercial sponsors.

Over the 4 days of the exhibition many visitors from 15 countries sought information from the personnel in the WOCE booth. Queries included what measurement equipment was being used in WOCE, specifications of research vessels, requirements for measurement accuracies, and availability of data. Visitors came from equipment manufacturers, universities, research institutions, government agencies, data centres, consulting companies, international and environmental organizations, insurance companies, foreign trade delegations, secondary schools and others. Several publishers expressed interest in future contributions from WOCE scientists and offered to publish proceedings of upcoming WOCE conference sessions.

Corporate sponsors of the WOCE IPO booth at OI ’94:
- Anderaa Instruments A/S
- Falmouth Scientific Inc.
- General Oceanics Inc.
- Guildline Instruments Ltd.
- MORS Environment Division
- Ocean Scientific International Ltd.
- Ocean Sensors Inc.
- Sea-Bird Electronics Inc.
- SeaScan Inc.
- Sensoren Instrumente Systeme GmBH
- Sippican Inc.
- Sparton of Canada
- Technocean Associates
- Tekelec Systemes
- The Tsurumi Seiki Co. Ltd.
- Webb Research Corporation
- R.M. Young Co.

The response to the exposure of WOCE at OI ’94 was excellent, and several sponsors of the booth reported that due to the increased visibility of their products in brochures available at the WOCE stand several new customers were directed to their exhibits at OI ’94. We encountered large public and commercial interest in WOCE and the IPO will be seeking further opportunities to sustain this interest in years to come.

The display material is now available for use at other events and will be shown next at the IOC Executive Council meeting in Paris. WOCE IPO is ready to provide the displays for anyone wishing to use them on similar occasions.

WOCE at The Oceanography Society Pacific Basin Meeting, Honolulu, 19–22 July 1994

Ilse Hamann, WOCE IPO

The Oceanography Society (TOS) co-sponsored and organised an international science and policy forum for Global Change programmes operating in the Pacific Basin. WOCE used the meeting to present new results and to review the progress of measurements in the Pacific. The opportunity was also taken to have an informal joint meeting of the CP1 and CP2 WGs during which demonstrations were set up to show the extent to which WOCE can make data sets available electronically to PIs.

The CP1/2 committee members discussed the planned merger of their two committees into a single Global committee focused on the analysis and interpretation of the global WOCE data set. The name Global Synthesis Committee was suggested. Tasks envisaged for the Global and Gyre-scale working groups were seen as:-

- Monitoring completion of Pacific and Indian field programmes,
- Developing plans for the Atlantic, monitoring implementation and identifying gaps,
- Stimulation and co-ordination of WOCE data synthesis,
- Developing a plan for assessing circulation variability,
- Formulating needs for measurement and modelling activities to follow WOCE.

Amendments to the proposed terms of reference for the Global and other WGs will be considered by the SSG at its October meeting in Kiel. It is planned for the first meeting of the Global group to be early in 1995.

Much discussion centred on the latter stages of the WOCE field programme and on the subsequent data analysis and interpretation. The timely provision of data products to PIs was seen as an immediate and important goal but one in which the PIs needed to be more pro-active by asking for what they would like to see. It noted that the Pacific WHP data were being made available to PIs via a password-regulated ftp and it was hoped that a similar provision would exist for the Indian Ocean data.

The demonstration of WOCE data systems went well and the WOCE information and data available on the Internet World Wide Web were explored. As yet information on the WOCE data centres are available on the WWW via the WOCE DIU and this can give access to the DACs and their data. The ease with which data are accessible varies from centre to centre but overall will surely improve.

In the TOS plenary sessions the interdisciplinary links between programmes became very obvious and stimulated considerable discussion. Many of the results reported showed how multiple data sets from field expeditions had been analyzed and, in some cases, merged and synthesized. For example, D. Karl's JGOFS summary of the results from more than 50 occupations of the Hawaii Ocean Time Series during the past 5 years showed how fluctuations of this oligotrophic ecosystem relate to gyre-scale changes of the circulation and water mass exchanges. J. Lupton (RIDGE/ODP) described how mid-ocean ridge processes along the East Pacific Rise can be traced in the temperature signatures and flow patterns of the intermediate and deep Pacific Ocean and how measurements of hydrothermal plumes can also be used to estimate mixing parameters in the deep ocean.

In two plenary talks a picture was given of the TOGA-TAO array observational system in the tropical Pacific. R. Knox outlined several components of TOGA that are likely to become part of an operational Global Ocean Observing System after 1994. His talk was complemented by E. Sarachik's description of the development of climate prediction systems. The talk covered techniques for initialization, data assimilation, the prediction of oceanic and atmospheric motions, plus the verification, dissemination and application of the predictions from coupled ocean-atmosphere models.

In the WOCE plenary session L. Talley gave a comprehensive synopsis of historical and recent observations of the Pacific circulation, highlighting ventilation of the intermediate waters. Her presentation of results was complemented by L.-L. Fu's talk on sea surface height variability from satellite altimetry as an indicator of changes in ocean circulation.

WOCE sessions were held on:-

- Large-scale tropical ocean measurements,
- Modelling of the Pacific Ocean general circulation, including a discussion on WOCE data resources,
- Observations of Pacific circulation and heat transport,
- The time-dependence of the circulation and water masses.

The moderate size of the whole meeting (several hundred participants) allowed for a good amount of time for discussions especially during the afternoons and in the poster area. It was overall a very successful meeting.

WOCE is a component of the World Climate Research Programme (WCRP), which was established by WMO and ICSU, and is carried out in association with IOC and SCOR. The scientific planning and development of WOCE is under the guidance of the JSC Scientific Steering Group for WOCE, assisted by the WOCE International Project Office. JSC is the main body of WMO-ICSU-IOC, formulating overall WCRP scientific concepts.

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Scientific material should not be used without agreement of the author.

We hope that colleagues will see this Newsletter as a means of reporting work in progress related to the Goals of WOCE as described in the Scientific Plan. The SSG will use it also to report progress of working groups, experiment design and models.

The editor will be pleased to send copies of the Newsletter to institutes and research scientists with an interest in WOCE or related research.